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NOTE ON MEASUREMENTS OF THE FILMS OF THE SOLAR ECLIPSE, MAY 9-8, 1948

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Abstract--Second and third contacts are studied by measuring the variation of the integrated light for the individual beads at their appearance or disappearance. The light variation is derived from the density variation. The density is measured radially through the image of the crescent. A calibration gives the relation between the density and the light which caused the density. By calculations based on the variation of light are found (a) the instant and the value of the minimum angle, as seen by the observer, between the centers of the Sun and the Moon at the eclipse; (b) the difference of the angular radii of the two bodies; (c) the relative positions on the Earth of observers at different stations along the eclipse. Furthermore, an improved knowledge of the limb of the Moon and of the limb darkening of the Sun can be obtained.

Although the eclipse of May 9-8, 1948, was annular, it could be valuable for geodetic purposes. It seemed therefore advisable that several expeditions should get in the shadow of the Moon to obtain whatever results the clouds might allow. Furthermore, it was believed that the handicap of possible cloudiness might be overcome by using airplanes flying above the clouds. Successful observations would lead to improved knowledge of the figure of the Earth, of the relative position of the observers, of the limb of the Moon, and of the darkening at the limb of the Sun.

The National Geographic Society sponsored the organizing and equipping of the various expeditions which took part in the work. The Army Map Service was one of the Governmental and private agencies contributing to the task and especially to the instrumental preparation for the observation. Seven ground expeditions went to selected sites in the Aleutian Islands (Alaska) and in the Far East [KINNEY, 1949]. Two of these, namely those at Rebun Jima, Japan, and Mergui, Burma, were able to operate well, while three other expeditions, those at Onyo, Korea, Bangkok, Siam, and Mount Moffett, Adak, could observe only a part of the eclipse. In addition, the eclipse was observed from two B-29's which flew along the eclipse path near the 180th meridian at 27 000 to 29 000 ft, held in their course by shoran.

The observations were made by a chrono-cinematographic method [BONSDORFF, 1944; LINDBLAD, 1944, 1945]. Thirty-five mm film was used with standard Wall and Mitchell movie cameras equipped with Goerz Artar lenses (about 47 inches) and was so set as to use the sound track for the time determination while taking the image of the Sun. In Rebun Jima, besides a Wall camera, use was made of a second movie camera, lent to the expedition by Bonsdorff of Finland who had designed and built that instrument for the observation of previous eclipses. A lens of about 80-inch focal length with a yellow filter was used with this camera at full aperture of about six inches. Neutral filters were employed with the other cameras. The Wall camera 47-inch lens at Rebun Jima was open about three inches.

The writer thought it might be interesting to work with spectrograms of the photosphere and the chromosphere (on movie film with the time recorded on the film) using a spectrograph with a curved slit (presenting the form of the image of the crescent as projected on the plane of the slit) or with two such slits, or two such spectrographs for each station. Time did not permit the preparation of these devices. Besides, it might be advisable to try that method with a total eclipse first.

Two time-recording lines were impressed along the sound-track region of the film. The chronometer tick made marks on these lines. To determine the correspondence between a sound-track mark and the frame which was simultaneously exposed, a series of spacing tests was made before the eclipse; the film was stopped with the shutter partly covering the gate; from the shutter position and the distance between the exposed frame and the point of the sound-track line which was exposed at the same time the relation between frame and time marks is derived. Another recording of both the chronometer ticks and radio signals on the drum of a chronograph afforded a means of correcting the chronometer time. In some of the films no linear sound track exists, but the time is recorded on them with a different kind of mark appearing over given intervals near the sprocket hole line on the film. In the airplanes a synchronized movie camera photographed the chronometer as well as the altitude, temperature, and shoran instruments. Time signals from WWV of the National

Bureau of Standards, rebroadcast from station KRHO, Honolulu, were used.

The films taken at the eclipse are measured to obtain the results. The film taken at Rebun Jima was 1000 ft long. Most of it is taken up with the terminal phases of the eclipse, which are to be reduced at the Georgetown Observatory, under the direction of Francis J. Heyden, by the method of the variation of the distance of the cusps, which method has already been successfully applied in that observatory.

The photometric measurements made on the central phases of two Rebun Jima films (one of them taken with a Wall camera and the other with a Bonsdorff camera), one film obtained on a B-29 plane by a Mitchell camera, and one on which the eclipse was photographed by a Mitchell camera at Mergui are the special object of this paper. Following the method of Banachiewicz, as described by KORDYLEWSKI, [1932], the second and third contacts are not considered as single contacts, that is, as if the limb of the Moon were smooth, but, since the limb of the Moon is irregular, the fact is taken into account that because of the irregularity the contacts are necessarily multiple. Therefore, the contact instants for individual beads (that is, the instants of appearance or disappearance of beads) and their position must be determined. Comparison with Hayn's charts of the profile of the lunar limb can thus lead to accurate determination of the relative position of the Sun and the Moon and of the difference of their apparent angular radii. (The manner of measuring the beads also applies to separations, that is, to parts of the crescent arc connecting two consecutive beads. One or more spots of each such part of the arc are measured in the same way the beads are measured.) Applying the method of Kordylewski by visual observation, with the aid of a magnifying glass, of the appearance time (second contact) or disappearance time (third contact) of a large number of beads and separations, a preliminary estimate of the Rebun Jima film was made in the Astro-Geodetic Section of this Service. Although the results do not give the expected accuracy, they can be considered as a first approximation, which should be greatly improved. For this purpose, on the initiative of John A. O'Keefe, measurements on small, uniform-density spots by a photometric process have been conducted.

Photometric method--Measurements of density are made through the width of the crescent at a given bead on a sufficient number of frames before and through disappearance of the bead for the east limb of the Moon, and on a series of frames through and after the appearance of the bead or separation for the west limb. The process is repeated for all beads and separations which are involved in the contacts. Each bead measured is run in a photometer so that a scanning spot sweeps through the crescent radially. A curve of density versus radial distance is drawn either automatically, when a recording instrument is used, or else by a point-by-point plot on the basis of a reasonable number of measurements made by photometric matchings through the crescent and also by determining the radial distance between the matchings. From the density-distance curve a curve

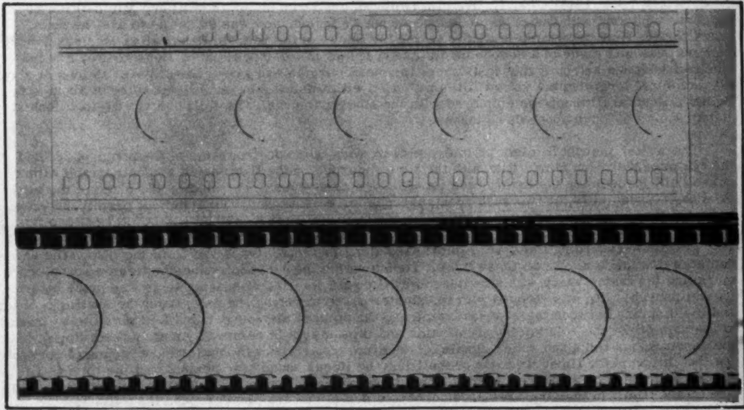

Fig. 1--A few consecutive frames from two eclipse films in natural size

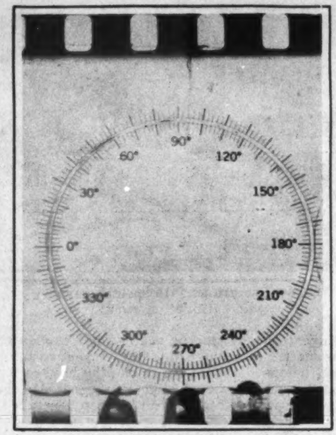

Fig. 2--An enlarged photograph of a frame with double-circle graticule superimposed upon the crescent for position identification

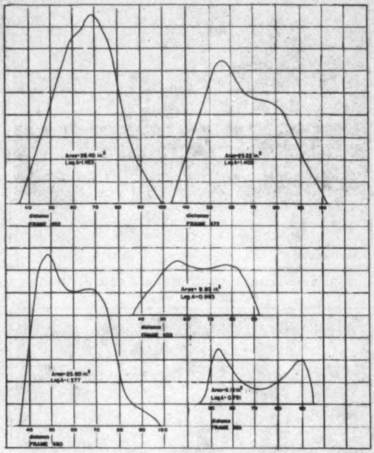

Fig. 3--Curves from measurements with the Fabry microphotometer

of the corresponding relative light intensities (that is, more exactly, of the illuminations which, received on the film, produced the measured densities) is obtained. This is done by means of a standardization curve giving the relation between density and illumination, and so prepared as to apply to the film which is measured. A gray scale was used; the density of its steps was accurately known by measurement with the microphotometers used in this work. By contact with this scale, prints on the same kind of film as that used for the eclipse were made, the other conditions in this process being carefully selected so as to give the same correspondence of density to illumination (characteristic curve) as in the case of the eclipse. (The original plan was to standardize during the eclipse by occasionally inserting a gradated film chart with density steps in the form of sectors. It was not carried out for various reasons. For instance at Rebun Jima, an accident in the field resulted in the destruction of the charts in the Wall camera.) The relation of the scale densities thus obtained with the relative intensities passed by the steps of the original gray scale yielded the standardization curve of the photographic emulsion of the eclipse film. Figure 1 is a photographic reproduction (natural size) of a few consecutive frames from two of the eclipse films Figure 2 is an enlarged photograph showing a frame with the crescent in a double circle graticule. In Figure 3 are shown some of the intensity versus distance curves from the beginning and some near the end of a series of frames measured for one of the beads. The areas under those curves are measured by means of a planimeter. A sufficient number of points may allow an approximation, for instance by substituting a broken line for the curve, deriving the probable slope of either extrapolated terminal side, and thus calculating the area without plotting the graph. This method is applied to abbreviate the work when tests by comparison with plotted curves show that the results remain within acceptable limits of accuracy. The way of integrating the light by using the areas of the curves gives a reliable quantitative basis for drawing a curve of the variation of light for each bead or separation at the central phases. Furthermore it allows all the effect on the film to be taken into consideration regardless whether the image is single or bifurcated. Bifurcation, which is observed in some of the films of this eclipse and which has also occurred in some photographs of previous eclipses, consists in obtaining on each frame two images of the crescent, one fainter than the other, instead of one image; that is, the image of the central phase of the annular eclipse, instead of being a single circle, also shows a second fainter circle of slightly displaced center. From observations and tests incidentally made during standardization work after the eclipse, it seems that the bifurcation of the crescent in its images is perhaps due to vibration, either resulting from the driving mechanism of the camera (or from the shutter in still cameras), or otherwise existing in the environment and transmitted to the camera. There are indications, however, that the

Fig. 4--Camera, coelostat and slit plate in calibration work

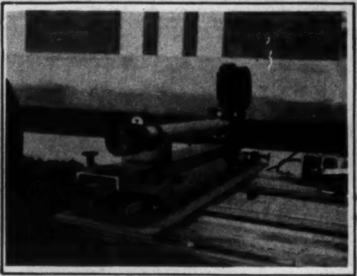

Fig. 5--Camera and its special support in calibration work

Fig. 6--Coelostat, slit plate and transit telescope in calibration work

bifurcation may also be due to other causes and the matter is subject to further investigation. But, independently of its cause, the bifurcation is taken care of when the light is integrated by the photometric method which has been described and no error in the measurements results from the image being double and not single.

A second kind of calibration by a method suggested by John A. O'Keefe is based on photographing a rectilinear transparent pattern (on opaque background) made of consecutive steps varying in width. The photographs are taken on film of the same kind as that of the eclipse, under similar conditions and so that even the greatest step width of the rectilinear slit is below the resolution power of the system. In this manner the variation of light from one step to another is directly as the variation of the widths of those steps. Thus, images of a linear shape, like those of the eclipse, are obtained, but of known photometric relation. This affords a series of comparison standards by means of which the crescent can be studied without neglecting the particularities of the emulsion which cause spreading of the image. It furthermore allows to take into consideration any intermittency effect possibly involved in the bifurcation of the image. Figure 4 shows equipment which was used to observe the eclipse, set for obtaining the standardization line. The camera, fitted with the 47-inch lens, is placed at a distance of about 100 ft from the slit near which the coelostat also is seen. In Figures 5 and 6 the two sets are shown separately. The camera with the tube carrying the lens (see Fig. 5) is placed on a support specially designed for these tests and consisting of three wooden boards so that an adjustment can be made in a simple manner to point to the coelostat. Setting screws allow a rotation about a horizontal axis near the lens, this axis being perpendicular to the direction of the axis of the lens and intersecting the vertical diameter line of the lens. A rotation about that vertical line was secured by a short brass shaft fastened to the middle board and rotating in a flat brass ring fastened to the lower board. Framed oblong rollers were placed between those boards near the other end and horizontal setting screws at that end. (A height adjustment can also be obtained.) Figure 6 shows the plate with the standardization line slit in front of the coelostat. A transit telescope mounted on a tripod allows the coelostat operator to observe an image in a finder over the lens tube of the camera in order to keep the image constantly in the field.

Another method providing the same effect, devised by the author, consists in making contrast positives of the crescent on film by contact and obtaining from these, by contact again, calibrated negatives using same film and sunlight as in the eclipse. The illumination producing the densities of these negatives is varied by varying the distance at which they are simultaneously exposed in a conical beam which extends beyond an image of the Sun at the focus of an appropriate converging lens.

Instruments--The Bureau of Standards has kindly placed at our disposal a Buisson and Fabry

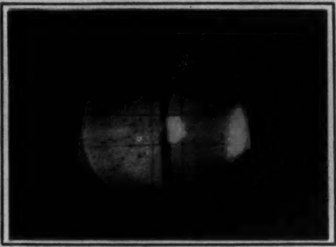

Fig. 7--Field of Fabry microphotometer with the usual size spot

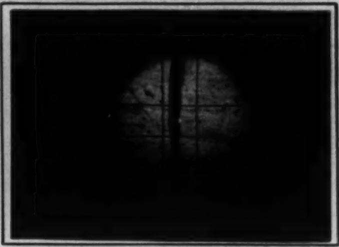

Fig. 8--Field of Fabry microphotometer with small dot spot

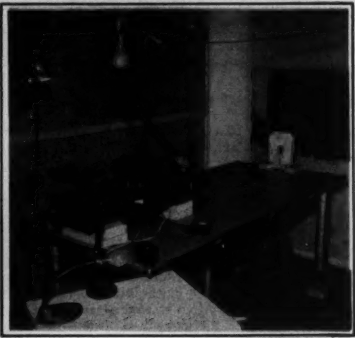

Fig. 9--Fabry microphotometer with added equipment

microphotometer and a recording Moll microphotometer. These instruments were originally designed for photometric work on different subjects, especially for the measurement of spectrograms. Modifications made on them by the writer adapted them to the measurement of the eclipse crescent. With the Fabry instrument, visual matching of spots produced by two sections of a divided monochromatic beam are made. Since the width of the crescent is of the order of 0.1 mm (see Fig. 1), the spot of the instrument must have a diameter much smaller than that length. But the smallest diaphragm of the instrument gave on the film an image larger than the width of the crescent. To obviate this difficulty, a diaphragm, with a mercury arc source behind it, has been placed at a distance from the instrument and is projected by an appropriate lens of sufficiently large relative aperture so that a dot of 0.01 mm diameter is obtained on the film. This way of proceeding gives to the matched semicircles a grainy aspect instead of their usual smooth uniform appearance when a larger spot is used. The grainlike markings, however, are not due to the grain of the film, nor is the matching rendered sensibly more difficult or uncertain. This has been confirmed by making measurements of gray scales using the small dot first, and then a large spot to repeat the measurements. Figures 7 and 8 show the field of the instrument with a small arc of the crescent as seen with the eyepiece when making settings; in Figure 7 a spot of the usual size is shown, while in Figure 8 is shown the small dot obtained with the modifications made for reducing the size of the spot. The spot in Figure 7 and the dot in Figure 8 appear white in these photographs, but in reality they are green because a green filter is used with the mercury arc light source. A fine relative motion of the spot, measured to 0.0001 inch through the width of the crescent, has been secured by fastening a micrometer to the carriage of the instrument. The micrometer drives a special sliding holder bearing the film. The holder is equipped with a small turntable so as to set the film in a manner such that the sliding motion causes the dot to travel radially across the measured part of the crescent. Another modification consists in interposing a transparent glass plate in the beam directed to the film. The plate is inclined to the axis of this beam so that reflection by this plate of an auxiliary light, put on during the settings, illuminates the film and its image is seen in the field. At the same time the photometric beam is allowed to pass through the plate and the dot which this beam forms on the film can be set at the place of the bead which is to be measured. Figure 9 shows the Fabry microphotometer. The luminous source (a mercury arc) is placed behind the diaphragm seen on the right. (The green filter normally placed in front of the diaphragm is not shown in this photograph.) The support of the projecting lens is seen at the end (right) of the instrument. The micrometer is near the middle of the instrument as seen in the picture. The interposed glass plate appears farther on in line with the handle of the micrometer.

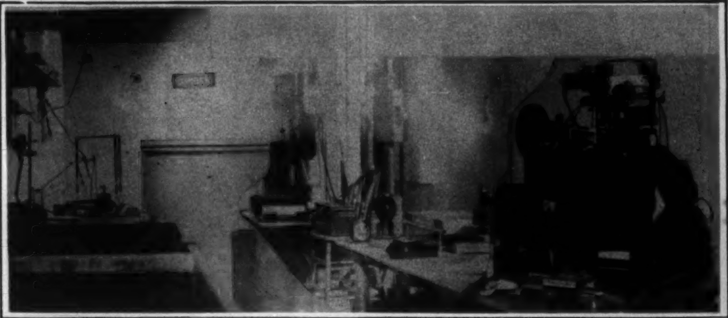

Fig. 10--Moll recording microphotometer and microgalvanometer with antivibration suspension

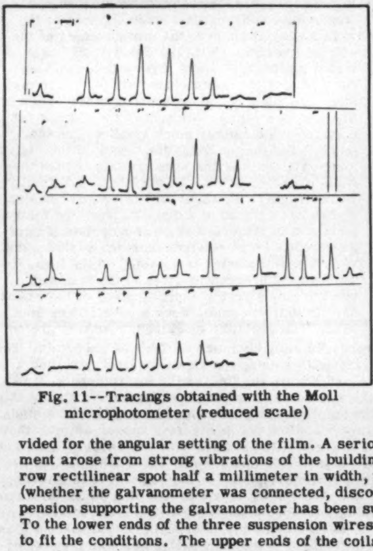

Fig. 11--Tracings obtained with the Moll microphotometer (reduced scale)

Analogous modifications have been made on the Moll recording microphotometer. The receiver in this instrument is a thermocouple actuating a very sensitive microgalvanometer, the spot of which traces a curve with ordinates proportional to transparency. The abscissas (radial width of crescent) are multiplied by 50 in the tracing. An extension has been added to the optical bench of the instrument to afford setting of the thermocouple at a distance allowing higher magnification of the crescent. The thermocouple slit is made very narrow and very short and the image of the crescent on the plane of that slit is considerably magnified so that a very small part of the surface of the measured bead is intercepted at any instant by the slit. The radial width of that part is very small compared to the radial width of the bead, and the arc covering the length of the slit is suitably smaller than the crescent arc occupied by the bead. A higher brightness tungsten-ribbon lamp with special lantern casing is occasionally substituted for the lamp of the instrument, or, in other cases, a high-brightness, small tungsten-coil lamp is used. Accessories, similar to those adapted to the Fabry instrument are provided for the angular setting of the film. A serious difficulty with the galvanometer of this instrument arose from strong vibrations of the building in which it is used. Instead of the expected narrow rectilinear spot half a millimeter in width, vibrations gave a blurred rectangle an inch wide (whether the galvanometer was connected, disconnected, or short-circuited). An antivibration suspension supporting the galvanometer has been successfully tried; it is a Julius-type suspension. To the lower ends of the three suspension wires coil springs have been added, carefully selected to fit the conditions. The upper ends of the coils are connected by three horizontal rods of aluminum forming a rigid triangle. Figure 10 is a photograph of the Moll microphotometer; on the left is seen a part of the antivibration suspension with the galvanometer in the middle of the brass platform of the suspension.

To obtain, for the same angle, a greater elongation of the spot along the microphotometer camera slot, the microphotometer is placed at a distance of 4 1/2 m from the microgalvanometer, this distance being greater than the usual distance. The distance of the illuminating lantern from the galvanometer is also increased, but instead of placing the lantern vertically over the galvanometer, a mirror is placed above the galvanometer and the lantern is placed a proper distance away. Also, a lens of a greater focal length than usual is inserted in front of the galvanometer (in the incident beam) to obtain, on the camera slot, a narrow lantern slit image of size about equal to that of the slit. The maximum elongation can thus be made to exceed considerably the length of the slot and the paper of the camera. The maximum or zero position of the spot is then recorded by observation and entered on the tracing paper extended, or else tracings obtained with different maximum elongations are related by means of suitable reference spots, the transparency of which is recorded in two of those tracings. If it becomes necessary, a still greater distance between galvanometer and camera is planned, using a broken line beam by the interposition of mirrors, and projecting, instead of the image of a slit, that of an incandescent lamp filament by use of an appropriate optical system. A camera with a longer drum would also be made. Figure 11 is a reproduction in reduced scale of tracings obtained with the Moll microphotometer from an eclipse film. After the curves are traced, corrections are made and the reductions are carried out in a similar manner to that described for the measurements made with the Fabry microphotometer.

Densities of all magnitudes occurring in this work have been measured with the two microphotometers as described. The crescent densities which were to be measured ran up nearly as high as 2. Gray scale densities and uneclipsed Sun disk densities, which were measured in connection with this work, went as high as 4.5 or slightly over.

Acknowledgments--The National Bureau of Standards contributed to this project by lending the instruments with which the measurements are being made. Lyman J. Briggs of that Bureau and of the National Geographic Society took an active part in the preparatory phases of the expedition and in the planning of the observations. His interest throughout the project has been a large factor in its success.

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THE EFFECT OF METEOROLOGICAL CONDITIONS ON THE MEASUREMENT OF LONG DISTANCES BY ELECTRONICS

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Abstract--In the measurement of long distances by electronic methods, meteorological observations are needed for two reasons: (1) The changing index of refraction of the atmosphere with altitude between the ground station and the aircraft bends the ray path, changing the length of the path, thereby necessitating a varying correction to reduce the measured distance to a geodetic distance. (2) A constant velocity of propagation of electromagnetic waves is assumed in the instrument design. The true velocity of the waves varies with changing meteorological conditions, and a correction, which is a function of the difference between the assumed and the true velocities, must be applied to reduce the indicated distance to the true distance. This paper discusses these two effects and methods currently in use for determining these corrections.

Introduction--All surveying operations are affected by atmospheric changes. The geodetic engineer observes theodolite directions through air of varying temperature, pressure, and moisture content. Therefore, theodolite directions are always subject to an error caused by varying refraction along the path from target to instrument. In conventional triangulation, only the horizontal component of the refraction or bending contributes to the error. No attempt is made to correct observations for horizontal refraction because of the difficulty of observing all of the meteorological changes along the ray path. In lieu of applying refraction corrections, the surveyor judges excessive refraction by large triangle closures and by the failure of the lengths of the sides to agree when they are computed through different chains of triangles. When the triangle closures or the side checks indicate excessive refraction, reobservation of the directions is necessary. At times when atmospheric conditions are unusual it is necessary to reject between ten and 50 per cent of the observations to meet triangle closure and side-check specifications.

When electronic instruments are used to measure distances the errors resulting from refraction must be analyzed in a different manner. Also it is possible to apply corrections to minimize the effects of atmospheric refraction. This is accomplished by: (1) evaluating the meteorological conditions by methods of observation; (2) computing the effective changes of the refractive index; and (3) computing the corrections in two parts, (a) a velocity correction and (b) a path-length correction. Before elaborating on these processes it is desirable to consider the early history of electronic surveying.

The first attempts to measure long distances with geodetic accuracy by electronic methods were undertaken during the latter stages of World War II. These attempts were initiated after the successful use of electronic blind-bombing instruments which allowed the release of bombs at a precomputed distance from each of two ground stations of known position. Geodesists were attracted by the potentialities of the bombing instruments and recognized the possibilities of reducing the accidental errors by multiple observations and by the adoption of systematic observing techniques. The obvious manner of using multiple observations for distance measurement was to fly the airplane across the line between two stations, continuously recording the distance from each. When the sum of the two air-to-ground distances reached a minimum, the airplane would be in a plane containing the two ground stations and the aircraft. This minimum sum, after applications of corrections, would very nearly equal the geodetic distance between the ground stations. The applicable corrections are: (1) correction for the true velocity of propagation of the radio waves as compared to the design velocity of the instrument; (2) correction for the change in path length caused by the bending or refraction of the ray along its path; (3) correction of the air-to-ground distance to reduce to the sea-level arc distance; and (4) correction for instrumental errors as determined by calibration.

The reduction of the air-to-ground distances by a geometrical correction was a simple problem. The problem of instrumental calibration and modification was more difficult. At best it can now be said that some success attended these efforts and that the pattern of future design and research was indicated. The design of observing methods was successful to the extent that measurements of the same distance could be repeated with considerable success. The problem which at first seemed most difficult to solve was that of computing a satisfactory velocity and path-length correction.

Electromagnetic waves travel at a constant velocity in a vacuum. The difficulty in air-to-ground electronic measurements is that the waves do not travel in a vacuum but in air of varying pressure, temperature, and moisture content. Obviously, corrections for these changes could not be incorporated in the instrumental design. The solution was to adopt a constant velocity in the instrument and afterwards to correct the observed values for velocity changes from this constant value by means of observed meteorological conditions in the air through which the waves traveled.

Radio or "wireless" telegraphy was first designed as a means of communication. The ultimate aim of the designers was clear reception over the longest possible distance. Consequently, it is not surprising that all early literature on radio-wave propagation was devoted to range and field strength and seldom referred to the velocity of propagation. Even after the advent of radar bombing techniques, where distances were measured by timing radio waves, the uncertainties inherent in the ballistics' properties of the bombs were greater than the propagational velocity uncertainties. It was quite satisfactory to use an average velocity for a particular area in the bombing computations.

During the war several important investigations of radio-wave propagation were made in which the atmospheric conditions were considered. Those studies were mostly confined to range, signal intensity, and attenuation with distance, and the velocity of propagation scarcely received mention. However, they presented empirical and theoretical relationships between the index of refraction and the atmospheric changes of pressure, temperature, and water-vapor pressure which were important in the velocity studies.

Radio waves may be propagated by means of the sky wave which is reflected from the ionospheric layers, or by the ground wave. The ground wave is composed of direct waves and surface waves. The surface wave travels along the surface of the Earth which functions as a conductor. Long waves of about 3000 m (100 kc/sec) can be propagated great distances in this manner. But as the wave length decreases the attenuation of the surface wave increases until, for wave lengths less than ten meters (30,000 kc/sec), the range of the surface wave is almost negligible. The velocity of the surface wave is affected in a complicated manner by the terrain over which it passes and consequently distance measurements by instruments using the surface wave are limited in accuracy. This paper is devoted to geodetic measurements and therefore a discussion of surface-wave velocity is beyond its scope.

In addition to the surface wave there is a direct or "line of sight" wave which travels directly from the transmitter to the receiver which is used for geodetic measurements.

The fundamental electromagnetic wave velocity relationship in a medium such as air, whose permeability is nearly unity, is

$$v = v_0/\mu = v_0/\sqrt{k} \qquad (1)$$

where v = the velocity in the air

v_0 = the velocity in a vacuum

μ = the index of refraction of air (ranging from 1.000000 in a vacuum to approximately 1.000500 in air at sea-level under certain extreme conditions)

k = the dielectric constant of the air

Obviously radio waves traveling between an airplane and a ground station travel through air in which the index of refraction not only tends to decrease with altitude but varies with changes in meteorological conditions. The changing index of refraction affects distance measurements in two ways: (a) the velocity changes from point to point along the path, and (b) the curvature of the ray also changes thereby affecting the path length. The latter effect can be considered as a part of the geometrical correction which reduces the observed distance to the geodetic distance.

First attempts to develop a satisfactory velocity correction based upon observed conditions were made during an extensive series of measurements by the U. S. Air Force under the direction of the senior author from 1944 to 1947. Upon conclusion of the tests it appeared that certain improvements in the method were desirable, and later both Canada and Australia continued studies along the lines recommended.

This paper will be confined to methods which are now considered to be sufficiently accurate for geodetic measurements when made with existing electronic instruments. For reasons of economy it will not always be possible to use the methods exactly as outlined.

The essential processes in determining corrections to long-distance electronic measurements made from aircraft are as follows: (1) The lapse rates of pressure, temperature, and water-vapor pressure over the path which the wave travels must be determined. (2) A relationship between the index of refraction (or the dielectric constant) of the air in terms of pressure, temperature, and water-vapor pressure must be chosen. (3) A satisfactory relationship between the index of refraction and the radius of curvature of the ray must be adopted. (4) A method of correcting the observed distance for curvature of the ray must be developed. (5) A satisfactory method of incorporating the values of the index of refraction into an average or integrated velocity along the ray path must be developed. These steps will be considered in order.

Meteorological observations--The meteorological observations may be made by either of two methods: (a) aircraft observations, or (b) radiosonde observations. The former method is favored because radiosonde observations, at present, are of somewhat lower accuracy than good aircraft psychrometric observations taken with calibrated thermometers. It is true that a correction for dynamic heating caused by variations in the airplane speed is needed in airplane psychrometric observations, but careful calibration and correction should reduce errors from this source, leaving only those errors inherent in the theoretical assumptions upon which corrections for dynamic heating are based.

The method of making airplane psychrometric observations adopted by the U. S. Air Force during the earlier stages of testing the equipment permitted the observations to be made at nearly the same time and area as the measurements of distance, a feature not always possible in utilizing the radiosonde observations of the Weather Bureau and the Air Force Weather Stations.

The method consisted of having a "weather airplane" collect the meteorological information starting approximately 500 ft above the level of one ground station. The plane then followed the approximate shoran ray path on a gradual ascent to an altitude about 1000 ft above the point of the shoran line-crossing observations. It next spiralled downward to about 500 ft above the surface below the point of the line crossing and then ascended in a spiral to the highest level of the line-crossing plane. Thereafter it gradually descended along the approximate shoran ray path to a point about 500 ft above the second ground station. During the entire flight, psychrometric and atmospheric-pressure observations were made at 500-ft intervals of elevation up to the 5000-ft level and at 1000 ft intervals above that level (see Fig. 1). The psychrometric readings were made to the nearest 0.1° C on calibrated wet- and dry-bulb thermometers. The atmospheric-pressure readings were obtained by converting pressure altimeter readings (with a setting of 29.92 inches of mercury) to millibars according to the design of the altimeter. The up-and-down spiral at the point of the line-crossing is not essential for the velocity correction and is now seldom used in the Air Force technique. It is important that the weather plane level off for a short period of time before each observation is made to eliminate hysteresis errors.

Knowing the mean-sea-level elevation of the ground station and having a ground-station weather observation at the time of the lowest aircraft observation, the altitude at which each weather observation is made can be computed from the following relationship

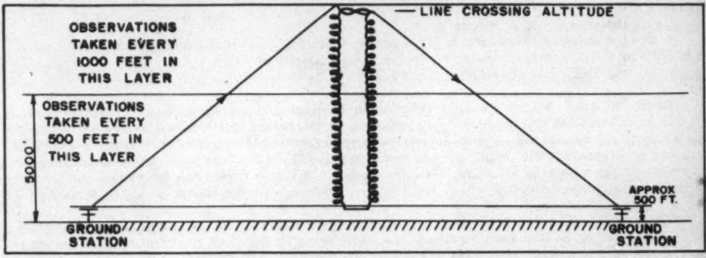

LINE CROSSING ALTITUDE
OBSERVATIONS TAKEN EVERY 1000 FEET IN THIS LAYER
OBSERVATIONS TAKEN EVERY 500 FEET IN THIS LAYER
5000'
APPROX 500 FT.
GROUND STATION
GROUND STATION

Fig. 1--Weather sounding procedure

$$\Delta z = 216{,}834\ \overline{T} \log_{10} (p_o/p_1)/[\overline{g}\ (1 - 0.378\ \overline{e}/\overline{p})] \qquad (2)$$

where Δz = thickness of the desired layer in feet
$\overline{g}$ = mean force of gravity of the layer in cm/sec^2
p_o = pressure at the lower level of the layer in millibars
p_1 = pressure at the upper level of the layer in millibars
$\overline{T}$ = mean temperature of the layer in degrees Kelvin
$\overline{e}$ = mean water-vapor pressure of the layer in millibars
$\overline{p} = p_o + p_1/2$

The psychrometric equation used during the Air Forces test was

$$e = e' - 0.000652\ p\ (t - t')(1 + 0.00102t') \qquad (2.1)$$

where e = water-vapor pressure of the atmosphere at a desired point, in millibars
e' = saturated water-vapor pressure as a function of the wet-bulb temperature, in millibars
t = dry-bulb temperature in °C
t' = wet-bulb temperature in °C
p = total atmospheric pressure in millibars

The above method of flying the aircraft weather sounding is not always operationally possible. The weather aircraft may not receive clearance for the changes of altitude because the desired flight path is near an airway. Consequently, it is sometimes necessary to resort to two or more soundings in the general area, supplemented by whatever radiosonde reports are available. Frequently the sampling of the atmosphere by such methods is entirely adequate. When a good network of radiosonde stations covers the area being surveyed the atmospheric conditions of the upper air may sometimes be adequately determined from upper-air charts.

The final result of the meteorological observations is a tabulation of temperature, pressure, and water-vapor pressure at calculated heights along the shoran ray path as well as a vertical atmospheric sampling at the point of the line crossing.

Index of refraction--There are a number of empirical relationships which express the index of refraction in terms of the total pressure, p, in millibars; the absolute temperature, $T = 273.16 + t°$ C; and the water-vapor pressure, e, in millibars. The different formulas differ principally in their constants. The National Bureau of Standards favors the following relationship

$$(\mu - 1)(10)^6 = 79\ p/T + 3.79\ (10)^5\ e/T^2 \qquad (3)$$

The following is the relationship as used for U. S. Air Force projects

$$(\mu - 1)(10)^6 = 76.43\ p/T + 3.767\ (10)^5\ e/T^2 - 8.925\ e/T \qquad (3.1)$$

In both of these formulas μ equals the index of refraction.

The estimated error of (3) is given by the Bureau of Standards as about four per cent. The uncertainty is due to errors both in the dry-air contribution and the water-vapor contribution. Therefore, until further research indicates that this uncertainty is lowered, the above expression must be accepted.

Curvature of the refracted ray--The curvature of the shoran ray affects the reduced geodetic distance in two ways: (a) the degree of curvature affects the reduction to a chord distance, and (b) it also affects the time the ray spends in any given altitude and consequently changes the velocity correction. It is important to point out that these two effects tend to compensate. When the curvature is greater than the assumed value, the reduced map distance will be too long but at the same time this assumption means that the ray will actually have traveled through a higher layer of atmosphere than was assumed. The velocity being faster in the higher atmosphere, too small a velocity correction will have been applied and hence the reduced map distance will be too short. It is this feature of compensation which permits the use of approximate methods with a relatively small error in the reduced distance.

The U. S. Air Force method of correcting for ray curvature--The USAF (U. S. Air Force) method is simple in principle and sufficiently accurate at the present time, considering present instrumental accuracy and probable error of the index of refraction formula. This method consists of applying a geometrical curvature correction based on the curvature of the shoran ray as given by

$$\bar{r} = R(2 + 1.9\bar{h}) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

where $\bar{r}$ = a mean radius of curvature of the shoran ray
R = radius of the Earth
$\bar{h}$ = average altitude of the shoran ray

Also $\bar{h}$ was derived from the following relationship

$$\bar{h} = K + (M_1/M_o)(H - K) - (M_1/2)(M_o - M_1)(1/R - 1/r) \ldots \ldots \ldots \ldots (5)$$

where K = height of the ground station
H = height of the airplane
r = 4/R to a first approximation
M_o = map distance
M_1 = geodetic distance from the ground station to a point where the vertical at $\bar{h}$ intersects sea level

The above definitions are illustrated in Figure 2.

Correction tables, based on (4) and (5) were computed, and using the tables the map or geodetic distance was corrected for the curvature of the shoran ray.

Canadian investigation of the U. S. Air Force method--The USAF shoran report took cognizance of the inexactness of (4) because it was a general assumption and did not allow for variations in the lapse rate of the index of refraction with altitude.

The Canadian investigation used the following relationship to compute the curvature of the shoran ray as a function of the refractive index lapse rate

$$1/r = dn/dh \ldots \ldots \ldots \ldots (6)$$

A curve-fitting method was used to fit the refractive index lapse rate to

$$n = 1 + A + Bh + Ch^2 \ldots \ldots \ldots (7)$$

where A, B, and C are constants determined by the curve-fitting process.

The elaborate method used to correct (6) to a straight line distance between the ground station and the aircraft will not be discussed in this paper. Only the results of the comparison between the broader USAF method and the more rigorous Canadian method will be detailed.

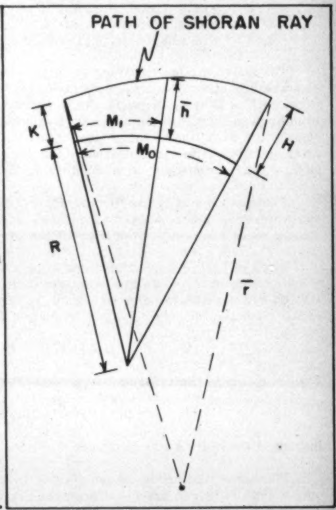


Fig. 2--Diagram illustrating terms used in geometrical curvature correction

Three atmospheres were investigated by the Canadians: (1) NACA (National Advisory Committee for Aeronautics) standard lapse rate of temperature with altitude (sea-level temperature of 15° C with a decrease of 2° C per 1000 ft) containing 60 per cent relative humidity at all levels; (2) NACA standard atmosphere with zero per cent relative humidity at all levels; and (3) an atmosphere which is 15° C warmer than the NACA standard with relative humidities according to Table 1.

After computation of the ray curvature a single radius of curvature was assigned to approximate the ray path. Table 2 shows the comparative results for the chord distance of 200 mi between the ground station and the aircraft. The maximum error of 0.0018 mi between the two methods occurs for atmosphere no. 3, which is an extreme case. It should be noted that this is only half the total error, as the aircraft flies between two ground stations. However, as was discussed earlier, the error in the velocity correction, for the same curvature error, tends to compensate.

Table 1--Assumed variation of relative humidity with elevation

Elevation MSL	Relative humidity
ft	pct
0	90
2000	72
4000	55
6000	42
8000	30
10000	23
12500	17
15000	12
17500	10
20000	10
25000	10

Table 2--Comparison of the results of arc-chord correction studies

Atmosphere	Radius		Arc-chord correction	
	Canada	USAF	Canada	USAF
	mi	mi	mi	mi
1	18,000	27,000	0.0010	0.0005
2	25,500	27,000	0.0005	0.0005
3	12,000	27,000	0.0023	0.0005

From the comparison table it can be seen that the USAF method is similar to the NACA dry atmosphere (no. 2), and also that there is little error in comparison to the NACA moist atmosphere (no. 1). Although the extremes of atmosphere no. 3 are encountered infrequently, it appears logical that if the constants of (4) were changed to approach the conditions of atmosphere no. 3 either of the two could be selected, reducing the error considerably. It is not felt that a third set of constants need be evolved for an extremely cold atmosphere. Any work performed in extremely cold climates would necessarily be done during the summer season when the lapse rate approaches the standard.

Kroll (Army Map Service) method of correcting for ray path curvature--The method of KROLL [1949] essentially integrates the basic differential equation of terrestrial refraction along the ray path and thus determines the velocity corrections and the geometrical correction simultaneously. The observed values of refraction with altitude are used and, therefore, the integration process must be done numerically. The solution is too involved to be practical with ordinary computing equipment. This method is the most elegant and rigorous of all methods suggested and should be employed in large scale projects where high accuracy is sought. However, Kroll concluded that for all ordinary atmospheric conditions the approximate computational methods of the USAF shoran staff were adequate.

The conclusions to be reached then are: (1) Until instruments are improved and better data for the index of refraction for moist air are acquired, the USAF approach to a ray-path curvature correction appears adequate. The more elaborate Canadian method is hardly justified unless the computations can be sufficiently simplified to reduce the computation time. (2) The rigid Kroll method should be employed on all large-scale projects where electronic computing equipment is available and the ultimate in accuracy is needed. The advantage of the Kroll method, aside from the rigidity, is that it serves as an independent check on the approximate geometrical and velocity corrections.

Correction for variations of the velocity of propagation--A great deal of experimental work has been carried out to determine the velocity of propagation of electromagnetic waves. As a result of the elaborate experiments of Michelson, and later of Anderson [DORSEY, 1944], a value of 299,776 km/sec has been almost universally adopted for the velocity of propagation of electromagnetic waves in a vacuum. Recently experimental results by different observers using widely varying methods have indicated that the above figure may be too low, but it is beyond the scope of this paper to discuss that subject.

As all electronic distance-measuring equipment is now designed, it is necessary to correct the observed distance, which is based upon a constant velocity, for the varying velocity caused by the changes in the meteorological conditions along the ray path.

In the shoran transmitters the design velocity is 186,219.0 mi/sec. This is equivalent to a velocity of 299,776 km/sec in a vacuum when corrected to standard sea-level conditions of 760 mm of mercury pressure and 0° C of dry air. Consequently, the shoran instrument will read correctly only when this one atmospheric condition exists at all levels between the ground station and the aircraft, a condition never realized since there is always a moisture, pressure, and temperature gradient with altitude.

In developing the velocity correction as used by the USAF it is easily shown that the velocity correction can be expressed by the following

$$\Delta M_v = \int_0^M \Delta \mu \, dm \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where ΔM_v = the velocity correction in miles
M = total length of shoran path
$\Delta \mu$ = the change in the actual index of refraction from the design index of refraction, or $(\mu = \mu_o)$
m = distance along shoran path

If airplane soundings are made in the manner described under "Meteorological observations," μ may be computed by (3). The expression (8) must be evaluated by numerical integration. The velocity correction can then be expressed as follows

$$\Delta M_v = \sum_{j=1}^{j=n} \overline{\Delta \mu_j} \, \Delta M_j \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where $\Delta \mu_j$ is the average value of $\Delta \mu$ in layer j, ΔM_j is the distance the ray travels in layer j, and n is the number of layers involved.

Obviously, for any given distance, there are an infinite number of ray paths depending upon the altitude of the airplane. Because the amount of refraction depends upon the altitude, the path curves more when the ray passes through the lower atmospheric layers. This in turn effects the path length and the velocity of propagation.

The numerical integration process can be greatly simplified by a tabulation of the integrated values of ΔM for a number of ray paths. It was found to be satisfactory in practice to compute eight different ray paths by (5). The ranges and altitudes covered by these ray paths are shown in Figure 3. Then for each ray-path curve values of the M and increments of M were computed for each 1000 ft of altitude. A sample of this tabulation is shown in Figure 4.

The value of M at an airplane altitude H frequently differed considerably from the map distance M_o. Therefore, in order to reduce ΔM_v to its correct value, (9) was rewritten

$$\Delta M_v = (M_o/zM) \sum_{j=1}^{j=n} \overline{\Delta kj} \, \Delta M_j \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

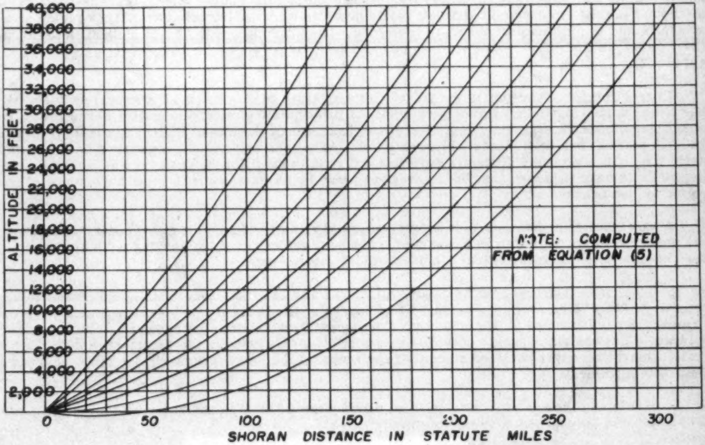


Fig. 3--Height of shoran ray path curves

SHORAN HEIGHT OF RAY PATH

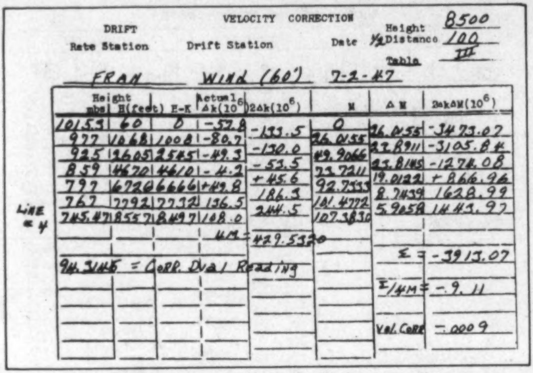
CURVE I			CURVE II			CURVE III		
$(N-K)(10)^{-3}$	M	ΔM	$(N-K)(10)^{-3}$	M	ΔM	$(N-K)(10)^{-3}$	M	ΔM
1	75.4708	16.9306	1	44.1021	18.5966	1	25.8817	16.7300
2	92.4014	13.4859	2	62.6987	14.2704	2	42.6117	13.3851
3	105.8873	11.5514	3	76.9691	12.0307	3	55.9968	11.4881
4	117.4387	10.2678	4	88.9998	10.5994	4	67.4849	10.2233
5	127.7065	9.3357	5	99.5992	9.5826	5	77.7082	9.3023
6	137.0422	8.6192	6	109.1818	8.8122	6	87.0105	8.5928
7	145.6614	8.0459	7	117.9940	8.2022	7	95.6033	8.0244
8	153.7073	7.5738	8	126.1962	7.7037	8	103.6277	7.5560
9	161.2811	7.1761	9	133.8999	7.2863	9	111.1837	7.1609
10	168.4572	6.8353	10	141.1862	6.9303	10	118.3446	6.8222
11	175.2925	6.5388	11	148.1165	6.6218	11	125.1668	6.5272
12	181.8313	6.2779	12	154.7383	6.3512	12	131.6940	6.2677
13	188.1092	6.0458	13	161.0895	6.1113	13	137.9617	6.0367
14	194.1550	5.8378	14	167.2008	5.8967	14	143.9984	5.8297
15	199.9928	5.6499	15	173.0975	5.7031	15	149.8281	5.6424
16	205.6427	5.4790	16	178.8006	5.5276	16	155.4705	5.4722
17	211.1217	5.3227	17	184.3282	5.3672	17	160.9427	5.3166
18	216.4444	5.1792	18	189.6954	5.2201	18	166.2593	5.1734
19	221.6236	5.0466	19	194.9155	5.0845	19	171.4327	5.0413
20	226.6702	4.9237	20	200.0000	4.9588	20	176.4740	4.9188
21	231.5939	4.8094	21	204.9588	4.8421	21	181.3928	4.8048
22	236.4033	4.7027	22	209.8009	4.7333	22	186.1976	4.6984
23	241.1060	4.6027	23	214.5342	4.6315	23	190.8960	4.5988
24	245.7087	4.5090	24	219.1657	4.5359	24	195.4948	4.5052
25	250.2177	4.4207	25	223.7016	4.4461	25	200.0000	4.4171
26	254.6384	4.3374	26	228.1477	4.3613	26	204.4171	4.3340
27	258.9758	4.2587	27	232.5090	4.2813	27	208.7511	4.2555
28	263.2345	4.1840	28	236.7903	4.2056	28	213.0066	4.1810
29	267.4185	4.1132	29	240.9959	4.1336	29	217.1876	4.1104
30	271.5317	4.0459	30	245.1295	4.0653	30	221.2980	4.0431
31	275.5776	3.9817	31	249.1948	4.0002	31	225.3411	3.9791
32	279.5593	3.9205	32	253.1950	3.9382	32	229.3202	3.9181
33	283.4798	3.8621	33	257.1332	3.8790	33	233.2383	3.8597
34	287.3419	3.8062	34	261.0122	3.8223	34	237.0980	3.8039
35	291.1481	3.7526	35	264.8345	3.7682	35	240.9019	3.7504
36	294.9007	3.7013	36	268.6027	3.7161	36	244.6523	3.6992
37	298.6020	3.6520	37	272.3188	3.6662	37	248.3515	3.6500
38	302.2540	3.6045	38	275.9850	3.6183	38	252.0015	3.6026
39	305.8585	3.5591	39	279.6033	3.5723	39	255.6041	3.5572
40	309.4176		40	283.1756		40	259.1613	

Fig. 4--Sample of tabulation of shoran height of ray

where Δkj is the average value of the dielectric constant in layer j (although μ is equal to $\sqrt{k}$, $\Delta\mu$ is almost exactly 1/2 Δk since μ and k are so close to unity).

Using (10) and the ray-path tables the numerical integration is greatly expedited.. An example of this numerical integration is shown in Figure 5.

Effect of meteorological fluctuations on the velocity correction--Figure 6 shows the graphical presentation of the differential analysis of the velocity correction with a plus one millibar or 1° C variation of pressure (p), temperature (t), and the wet-bulb temperature (t′), as prepared in conjunction with C. G. Purves, Meteorologist, U. S. Air Forces. This analysis is for varying aircraft altitudes and four different atmospheres. The outstanding feature of this analysis is the compensating effect of like sign variations in t and t′. If the NACA standard atmosphere, with an average moisture content for the Northern Hemisphere, were used as a basis of comparison any actual atmosphere which is colder than the standard would probably be dryer, and conversely, any atmosphere which is warmer than the standard atmosphere would probably be more moist. This excludes abnormal atmospheres such as desert climates. Because of this compensation the maximum deviation from the above standard atmosphere, over a maximum distance of 400 mi between ground stations would probably be 0.006 mi. If an average atmosphere for any given area for a particular month were used it is probable this deviation could be reduced to about 0.002 mi over the same distance. With shorter distances between ground stations the error would be proportionately less.



VELOCITY CORRECTION

DRIFT
Rate Station: FRAN
Drift Station: WIND (60')
Date: 7-2-47
Height: 8500
½ Distance: 100
Table: III

Height mbs	H(feet)	E-K	Actual Δk(10⁶)	2Δk(10⁶)	M	Δ M	2ΔkΔM(10⁶)
1015.3	60	0	-52.8	-133.5	0	26.0155	-3473.07
977	1068	1008	-80.7	-130.0	26.0155	22.8911	-3105.84
925	2605	2545	-49.3	-53.5	49.9066	23.8145	-1274.08
859	4670	4610	-4.2	+45.6	73.7211	19.0122	+866.96
797	6726	6666	+49.8	186.3	92.7333	8.7439	1628.99
767	7792	7732	136.5	244.5	101.4772	5.9058	1443.97
745.47	8557	8497	108.0		107.3830		

LINE = 4

4M = 429.5320

Σ = -3913.07

94.3145 = Corr. Dual Reading

Σ/4M = -9.11

Vel. Corr -.0009

Fig. 5--Sample computation of velocity correction

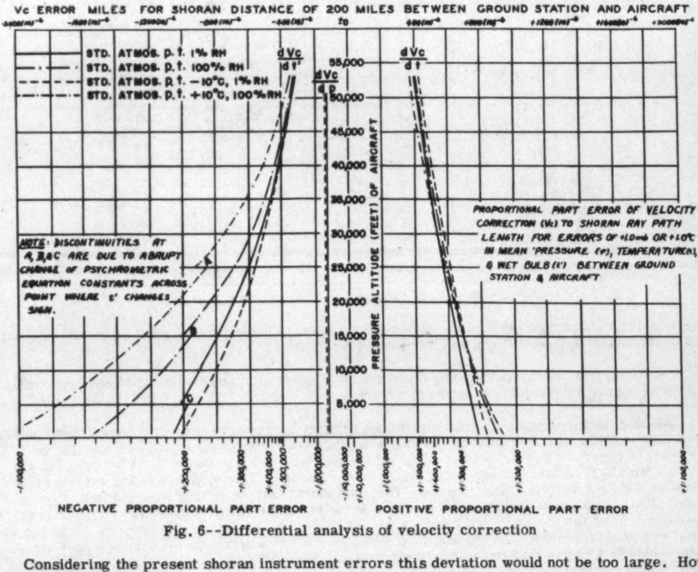


Fig. 6--Differential analysis of velocity correction

Considering the present shoran instrument errors this deviation would not be too large. However, with the inevitable progress in the instrument design more accurate velocity corrections would be necessary.

Analysis of errors--The errors due to uncertainty of the velocity of propagation in a vacuum and to the uncertainty of the index of refraction of moist air are probably greater than the relative errors of individual ray path and velocity corrections.

Table 3--Velocities of wave propagation

Year of publication	Observer	Length	Velocity in vacuo	Method
		M	km/sec	
1879	Michelson[a]	600	299,910 ± 50	Rotating mirror
1882	Newcomb[a]	4000	299,860 ± 30	Rotating mirror
1902	Perrotin[a]	46000	299,901 ± 84	Toothed wheel
1906	Rosa and Dorsey[a]	. . .	299,781 ± 10	Ratio of e.s.u to e.m.u.
1924	Michelson[a]	35000	299,802 ± 30	Rotating mirror
1926	Michelson[a]	35000	299,796 ± 4	Rotating mirror
1929	Mittelstaedt[a]	250	299,778 ± 20	Kerr cell-photo cell
1935	Michelson, Pease, and Pearson[a]	15000	299,774 ± 11	Rotating mirror in vacuo
1937	Anderson[a]	170	299,771 ± 15	Kerr cell-photo cell
1940	Hüttel[a]	48 to 118	299,768 ± 10	Kerr cell-photo cell
1941	Anderson[a]	170	299,776 ± 14	Kerr cell-photo cell
1948	ESSEN	. . . .	299,792 ± 9	Resonance in wave guide
1949	ASLAKSON[b]	. . . .	299,792 ± 1	Shoran
1950	BERGSTRAND	9000	299,793.1 ± 0.25	Kerr cell-photo cell

[a] See DORSEY, 1944.
[b] 47 distances varying from 67 to 367 mi.

The uncertainty of the velocity of radio waves in a vacuum may be very large. Table 3 shows all of the results which have been published since Michelson's first observation in 1879. BIRGE [1943] analyzed all previous measurements and determined a statistical value of 299,776 ± 3 km/sec. In the light of some recent values this now seems questionable. In fact, it appears probable that an error at least as great as 1:30,000 may exist in any statistical value based on previous observations.

The Bureau of Standards has estimated the uncertainties of the constants of the index of refraction (Eq. 3) to be as follows:

Dry air contribution to $(\mu - 1)$	5 per cent uncertainty
Moist air contribution to $(\mu - 1)$	2.5 per cent uncertainty
Weighted error of Eq. (3)	4 per cent uncertainty
Errors due to errors of measurement	3 per cent uncertainty
Total error of $(\mu - 1)$	7 per cent uncertainty

This above uncertainty of seven per cent is based on balloon or radiosonde observations. When airplane psychrometric observations are made with standardized thermometers the uncertainty is considerably less and probably is no greater than one per cent. It is, therefore, believed that the uncertainty of $(\mu - 1)$ is probably about five per cent. If $250 (10)^{-6}$ is taken as a mean value of $(\mu - 1)$ the uncertainty of the velocity correction would be about 0.0012 mi. The Canadian estimate of the accuracy of the velocity correction is somewhat better. They conclude that the velocity figure is accurate to 0.0003 mi. Probably the true estimate lies somewhere between these two values.

Conclusions--It has been shown that there are practical methods of correcting long-distance electronic measurements for variations in meteorological conditions. The best proof that the computations are practical rests in the fact that they have been reduced to standard forms by the U. S. Air Force, and that knowledge of the theory and mathematics behind them is not a necessity for their completion.

In the foregoing discussion, the meteorological problems in electronic distance measurements have been limited to the frequencies peculiar to shoran or from about 220 to 350 megacycles per second. For higher frequencies the problems caused by trapping in ducts increases and the sounding intervals would have to be more frequent. Continuously recording psychrometric equipment is being designed but at the present time is far from satisfactory.

The necessity for further research is clear. The most important present need is for better determinations of the velocity of propagation of radio waves in vacuuo and of the dielectric constant of moist air. The recent interest that has been awakened in both subjects is encouraging.

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HIGH-LOW QUARTZ INVERSION UP TO 10,000 BARS

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Abstract--The high-low quartz inversion temperature has been measured up to 10,000 bars. The relation of change of the inversion temperature with pressure to Earth-structure problems is discussed. Apparatus which has a working range up to 1400° C and 10,000 bars is described.

Introduction

Renewed interest in the theory that one of the changes in the velocity of seismic waves may be the result of the change at depth from low to high quartz has given rise to the need for additional data on the effect of pressure on the high-low quartz inversion temperature. GIBSON [1928] published values for the change of the quartz inversion up to 2640 bars. (1 bar = 1.0197 kg/cm^2 at gravity = 980.665 cm/sec^2 = 0.987 normal atmospheres = 10^6 dynes/cm^2.) The present work has yielded values up to 10,000 bars.

Description of apparatus

Pressure system--The pressure system (see Fig. 1) was designed by the writer and is based almost entirely on the apparatus constructed in 1910 and remodeled in 1933 by P. W. Bridgman [BIRCH and LAW, 1935]. The advantages gained by the new design will be apparent from the

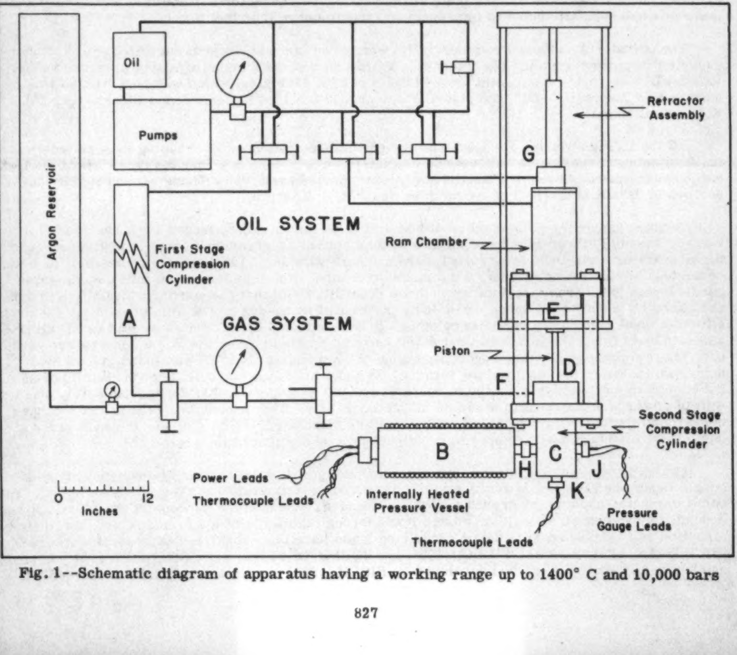
Oil
Pumps
Argon Reservoir
OIL SYSTEM
First Stage Compression Cylinder
A
GAS SYSTEM
Retractor Assembly
G
Ram Chamber
E
Piston
D
F
Second Stage Compression Cylinder
B
C
H
J
K
Power Leads
Thermocouple Leads
Internally Heated Pressure Vessel
Pressure Gauge Leads
Thermocouple Leads
0
12
Inches

Fig. 1--Schematic diagram of apparatus having a working range up to 1400° C and 10,000 bars description. The inert gas argon was used to transmit the pressure. Argon is particularly useful for high pressure experimentation at high temperatures because it does not form compounds with the metals in the containing vessel; it has a slow rate of diffusion through metal; it has a smaller compressibility than helium, nitrogen, or hydrogen; it is readily available in a high degree of purity (particularly free of H_20 and 0_2); and, furnace windings appear to suffer less embrittlement in argon. Compression of the gas is done in two stages. Argon at tank pressure, about 150 bars, is released into cylinders A, B, and C by means of commercially available, high-pressure (4200 bars), leather-packed, needle-type valves. Oil is pumped into cylinder A acting on a packed piston which separates the oil from the gas. In this manner the gas in cylinder A is forced into cylinders B and C until the pressure reaches 2000 bars, which is the limit of the commercial pump. To speed the first stage a large capacity pump is used up to 400 bars. These operations complete the first stage of compression. To reach higher pressures, the volume of the system is further reduced by advancing the piston D into cylinder C. This is done by pumping oil into the ram chamber actuating ram E. The ratio of the area of the ram, three inches in diameter, to that of the piston, three-fourths of an inch in diameter, is 15:1. Using the same pump, a maximum pressure of 30,000 bars is theoretically possible, but the limitations imposed by the free space in cylinder B and in the connectors, the friction on the ram and piston, and the strength of the chambers permit operation only at much lower pressures. Within an hour after assembly 15,000 bars can be obtained; a working range of 10,000 bars has been chosen arbitrarily. As the piston D moves down into the second-stage compression cylinder C, the piston passes the opening F, thereby confining the pressures above 2000 bars to cylinders B and C and protecting all other parts of the system. By use of a pump having a working range of twice that of the pumps designed by Bridgman, the size of intensifier has been reduced to roughly half, making construction and handling considerably easier.

The intensifier is provided with an opposing cylinder G to back off the ram in case of loss of pressure due to a leak or an explosion. Three major explosions have more than justified surrounding the apparatus with heavy steel plate. (Two explosions of unknown cause resulted in the splitting in two of the connector H and the calibration vessel. The second-stage compression cylinder burst irregularly from a point at the seat of the connector H packings. From hardness tests this has been attributed to improper heat treatment of the steel billet.)

The cylinder A, obtained commercially, was bored, ground, lapped, and fitted with a rubber-gasketed (neoprene) piston. The intensifier cylinders and the internally heated pressure vessel (bomb), B, were made from solid forged billets of SAE 4150 steel which was heat treated to a hardness of Rockwell C-40. The piston D was ground from a glass-hardened (Rockwell C-65) Ketos steel round.

All the fittings which were used with the chrome-molybdenum steel tubing (one-sixteenth inch inside diameter, one-fourth inch outside diameter) were of the cone-in-cone type. All of the highest pressure packings were of the Bridgman unsupported area type. These are adequately described by BRIDGMAN [1931, for examples see Fig. 3, 7, and 8].

Furnace assembly--The bomb, 6 1/2 inches in diameter and 18 inches long, has space for a furnace assembly three-fourths of an inch in diameter and eight inches long. A platinum-wound furnace having a six-inch, thin-walled, ceramic core with an inside diameter of one-half inch was cemented (Norton RA no. 98) into a stainless steel tube. No other insulation than the cement is used. It was found from previous experience [YODER, 1950] that the standard insulations which are based on porous dead space are quickly penetrated by the hot gas at high pressure. The most effective insulation has been shown by others to be fired soapstone. This was used to fill all free space in and around the furnace to cut down convection arising from the large temperature gradient. On searching with a thermocouple, a zone of even heating (± 5° C) was found to exist over some two inches of the length of the furnace. In about six hours the outside of the bomb became hot enough to melt solder when the temperature at this hot spot was 800° C; approximately one kilowatt of power was required to maintain this temperature. This necessitated the use of a copper coil around the bomb through which cold water was circulated. By this means the ends of the bomb were maintained at a temperature only slightly above that of the room.

Insulation of electrical leads--Three continuous, gas-tight, electrically-insulated, thermocouple leads are required in addition to one insulated, gas-tight lead for the furnace winding. The bomb itself was used as the ground lead to the furnace. Because the success of the entire apparatus depends on passing electrically insulated leads through the walls of the pressure vessels, their construction will be discussed in detail. Insulated leads have been described by several workers [BRIDGMAN, 1931; ADAMS, WILLIAMSON, and JOHNSTON, 1919; and GORANSON, 1931]; however, another very successful method developed by BIRCH [1932] has been only briefly presented. The

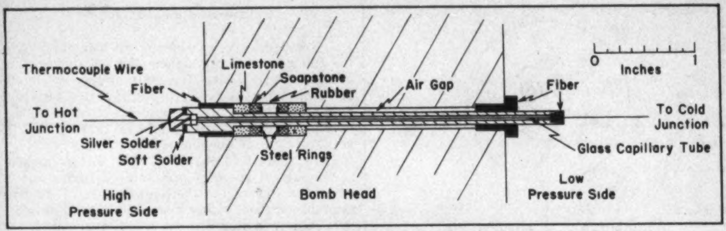

Fig. 2--Method for passing continuous, insulated, electrical leads through wall of high pressure vessel

method used here, based on a combination of Birch's design and Adams' packings, is given in Figure 2. The rod through which the thermocouple wire passes is of SAE 4140 steel heat treated to a hardness of Rockwell C-40. (Solid rods are used for power leads.) After haat treatment the 3 3/4-inch rod is drilled from both ends with a one-sixteenth-inch twist drill. "Walking" of the twist drill can be troublesome; however, a modified gun-type drill can be made which will drill a straight hole up to six inches in length. The drilled rod, which has usually warped in heat treatment, is put on centers and the rod turned or ground to the final shape. The packings are assembled on the rod after the large end is tinned. The assembled rod is inserted into the hole in the head of the bomb, the oversized rubber washer being punched into position. The unit is arbor-pressed into the seat for final sealing.

The thermocouple wire is cleaned with crocus cloth and passed through the small mushroom-shaped button which has been drilled with a no. 80 drill (0.0135 inch) and its surface coated with silver solder. The wire is then silver soldered in place. This step is done by holding the button, surrounded by a small strip of asbestos paper, in a suitable clamp. An oxygen - natural gas torch having a blue cone no greater than one-sixteenth inch long is played on an exposed side of the button until the silver-solder wire ring which has been placed around the wire is melted. This operation can be aided with a drop of flux (borax). The button is then tinned and soft-soldered into place. The solder, under pressure, acts as a soft gasket. A glass capillary tube protects the wire from further contact with the insulated rod. This gives a continuous, electrically insulated, gas-tight thermocouple lead.

One possible extraneous source of emf in this type of lead is from the inhomogeneity in the wire which results from surface alloying of the wire at the point of solder. These inhomogeneities give extraneous emf's only to the extent that there are temperature differences across the inhomogeneities. Another source of extraneous emf is that caused by the stress gradients set up in the wire at the button. This effect is probably exceedingly small. There was at least one megohm resistance between the bomb head and each lead. It was found necessary in Washington, D. C., to store the head of the bomb in a desiccator to retain the high resistance.

Temperature measurements

Iron-constantan thermocouples were used to measure the temperature at the center of the quartz sample and the difference in temperature between the quartz sample and the alumina reference. The arrangement of the junctions in a nickel block is shown in Figure 3. The use of the nickel block, a long zone of even heating, and the filling of all free space in the furnace reduced the total variation of temperature within the block to less than 0.1° C. The couples were replaced for each series of runs from the same spools of wire. A couple made from these spools of wire has been calibrated by the Pyrometry Section of the National Bureau of Standards for this work. Calibration of each couple was not necessary because a base point was established for each series of runs, a method which will be described subsequently. BIRCH [1939] investigated the effect of pressure on the thermal electromotive force of two other couples. From a consideration of his data, it may be stated that the decrease in emf at 800° C and 10,000 bars was probably of the order of 30 to 40 microvolts (0.5° C). The results to be presented can be corrected when the exact effect is known.

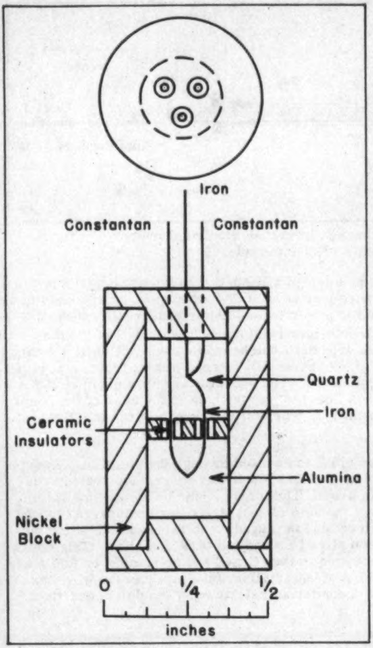

Fig. 3--Arrangement of junctions in nickel block containing quartz sample and alumina reference

Pressure measurement

The pressure was measured indirectly by the change in the resistance of a silk-covered manganin wire coil. The coils of approximately 100 ohms resistance were wound with 0.004-inch diameter wire from the same spool. Temperature and pressure seasoning was carried out according to the suggestions of ADAMS, GORANSON, and GIBSON [1937]. The coil is housed in the second-stage compression cylinder at point J in Figure 1. The temperature of the coil is obtained from a thermocouple imbedded in a hole in a dead plug at K; it rarely increased more than a degree during a given series of runs. The effect of one degree temperature on the pressure coefficient of manganin has been shown to be negligible. One lead of the coil is brought through an insulated stem in the gage plug, the other is silver soldered to ground. The change in resistance of the coil was measured by means of a modified type of Wheatstone bridge with four equal fixed arms such as used by ADAMS, WILLIAMSON, and JOHNSTON [1919]. In this bridge the usual galvanometer is replaced by a potentiometer. The coils were calibrated in terms of the freezing pressure of mercury at zero degrees (7492 bars) and the transformation pressure of CCl_4 I→II (3326 bars) at 20° C as given by BRIDGMAN [1911, 1914]. The circuits were arranged so that one microvolt on the potentiometer was equal to approximately half a bar. Error in the absolute pressure may be as great as ten or 20 bars at 10,000 bars, owing to uncertainties in the pressure scale.

Materials used

The quartz was collected by M. L. Keith and O. F. Tuttle from the central core of the pegmatite mass at the Etta Mine near Keystone, South Dakota. It was selected for this work mainly because its temperature of inversion at atmospheric pressure lies approximately midway in the range of temperatures of inversion of the many quartz samples examined by Keith and Tuttle [TUTTLE, 1949]. Further, its heat effect on inversion is of a simple nature; that is, its differential heating curve near 573° C consists of a single, smooth peak which shows no indication of drift during repeated heatings and coolings. By comparison with the known inversion temperatures of three reference materials, the temperature of the beginning of inversion on heating of the Etta quartz was found by Keith (personal communication) to be 572.3° ± 0.2°. The reference materials were potassium sulphate and Lake Toxaway quartz, the inversion temperature of which was determined by J. S. Burlew, and quartz crystal B, the inversion temperature of which was determined by BATES and PHELPS [1927]. The quartz was crushed in a steel mortar to pass 35 mesh and the material retained on 200 mesh was used. It was then treated with boiling HCl for 30 min, washed, and dried at 110° C. Approximately 0.3 gram was tapped into a compartment in the nickel block.

The alumina which was used as a reference substance for the differential thermal effects was obtained from Norton Company (120-mesh, electrically fused, crystalline alumina).

Procedure

After assembly of the apparatus the inversion of quartz was run at atmospheric pressure in the following manner. The temperature of the quartz was brought to within 10° of the inversion temperature. By means of a motor-driven, variable-speed, slide-wire resistor in the furnace circuit, a heating rate of two to three degrees per minute was established. Readings of the temperature

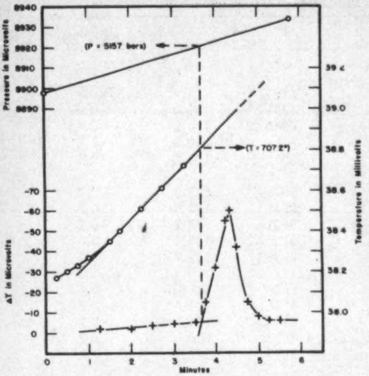

Fig. 4--Typical plots and constructions used to determine the pressure and temperature at inversion of low quartz to high quartz

of the quartz and of the difference in temperature between the quartz and alumina were read every 15 sec. A typical plot is given in Figure 4. The inversion point was assumed to correspond to the intersection of the tangent to the curve of departure with the base line. The average of four such runs and constructions determined the base point; that is, the temperature of the beginning of inversion from low to high quartz at atmospheric pressure. All further runs at the various pressures for a particular setup of apparatus were referred to this point. This base point was assigned the value of 572.3°, which was carefully determined by Keith in the manner described in the preceding section. Having determined the base point, the pressure was raised to the desired value. In addition to the above procedure the pressure was read at some convenient time after the heating rate was established and immediately after the inversion was completed. The rise in pressure, due to the increase in temperature, was assumed to be linear between readings. At the highest pressures the differential base line varied some 20-30 microvolts (not more than 0.5°); the variation is reflected in the somewhat large deviations in the results.

Results

Five successful experimental setups resulted in some sixty determinations (see Table 1) of the high-low quartz inversion temperature under pressures up to 10,000 bars. Through the kindness of Franz L. Alt, Assistant Chief of the Computation Laboratory, National Bureau of Standards, the data have been expressed by

$$\Delta T = -1.6 + 2.871 \times 10^{-2} P - 4.284 \times 10^{-7} P^2$$

Statistical tests show higher-order terms are not required. The deviations of the observations from the calculated curve are given in Table 1. The calculated inversion temperature at even thousands of bars is given in Table 2. The initial pressure effect is about 29×10^{-3} deg/bar and the effect at 10,000 bars is about 20×10^{-3} deg/bar. It should be realized that the equation should be used only in the experimental range since the arbitrary choice of representation implies properties for which there is no factual basis. For example, at 33,500 bars the temperature of inversion would appear to reach a maximum. Although such a property has been demonstrated for at least one solid transition, HgI_2 [BRIDGMAN, 1931, p. 245], and the present data do show curvature towards the pressure axis, the implication requires experimental proof.

Heat of transformation

Using the value of dT/dP near zero pressure, the absolute temperature of inversion T, and the volume change ΔV, it is possible to calculate the heat of inversion ΔH from the Clapeyron equation

$$dT/dP = T\Delta V/\Delta H$$

However, the volume change is almost impossible to determine with any degree of accuracy since quartz continuously increases in volume at an increasing rate to the inversion point [DAY, SOSMAN, and HOSTETTER, 1914, Fig. 6]. Here a sudden or discontinuous change is thought to take place and has been estimated by SOSMAN [1927, p. 364] to be 3.25 cc/kg. Using

$$dT/dP = 28.7 \times 10^{-3} \text{ deg/bar}$$

$$\Delta V_{\text{instantaneous}} = 3.25 \text{ cc/kg}$$

$$T = 845 \text{ K}$$

Table 1--Observed change in inversion temperature of quartz with pressure

P	Δ t	$t_{obs}-t_{calc}$	P	Δ t	$t_{obs}-t_{cale}$
bars	° C		bars	° C	
0	0	1.6	4337	114.7	-0.2
524	12.8	-0.5	4339	114.0	-0.9
528	12.8	-0.6	4340	114.5	-0.4
531	13.5	0	5014	130.3	-1.3
534	13.5	-0.1	5020	131.2	-0.5
547	14.0	0	5025	132.0	0.2
914	23.9	-0.4	5131	135.0	0.6
918	23.9	-0.5	5131	134.2	-0.2
1115	30.3	0.4	5136	135.1	0.6
1117	30.7	0.7	5138	135.2	0.6
1118	30.2	0.2	5139	135.0	0.4
1121	30.3	0.3	5155	134.4	-0.6
1141	30.8	0.2	5157	134.9	-0.2
1147	31.4	0.6	6177	160.6	1.2
1153	30.8	-0.1	6179	160.6	1.2
1865	50.1	-0.3	6179	160.9	1.5
1916	51.5	-0.3	7427	190.3	2.3
1925	52.4	0.3	7488	193.4	4.0
1933	51.4	-0.9	7540	194.0	3.5
2082	55.3	-1.0	7540	191.0	0.5
2087	56.2	-0.2	8612	211.4	-2.5
2093	56.7	0.1	8628	213.6	-0.6
2119	57.2	-0.1	8643	213.1	-1.4
3159	84.1	-0.7	8682	210.5	-4.9
3162	84.6	-0.3	8736	212.7	-3.8
3253	86.8	-0.4	9802	241.1	2.4
3254	87.2	-0.1	9840	239.6	0.2
4317	114.7	0.3	9895	242.4	1.9
4325	114.9	0.3	9909	240.7	-0.1
4334	113.7	-1.1	10000	242.2	-0.5

Table 2--Temperature at which high-low quartz inversion takes place at various pressures

P	Present work	Gibson
bars	t ° C	t ° C
0	572.3	573
1000	599	595
2000	626	618
3000	653	643
4000	679	(671)
5000	704	(699)
6000	728	(730)
7000	751	(762)
8000	773	(796)
9000	794	(831)
10000	815	(869)

the heat of inversion is calculated to be 2.3 cal/gm. This is low compared to the calorimetrically determined heat of transition: 4.3 cal/gm, [White in paper by WRIGHT and LARSEN, 1909]; 4.2 cal/gm, [COHN, 1924]; and 4.8 cal/gm [KELLEY, 1949]. Sosman's most probable estimate in 1927 was 2.5 cal/gm. However, it is to be pointed out that the calculated heat of inversion is the instantaneous heat effect or anomalous change of enthalpy at a point. This value is comparable to the calorimetrically determined values only if the latter are measured at a point and are not bulk values over a finite temperature interval [STEINER, 1941]. In view of the fact that the calculated value is smaller than those determined calorimetrically, it is suspected that the latter do represent a bulk value rather than the value at a point. On these grounds, the suggestion was made by L. H. Adams that if the bulk volume change were used in the calculation, the heat of inversion obtained would be comparable to the calorimetrically determined values which may represent a bulk heat effect. If the specific volume of quartz is plotted as a function of temperature, and two straight lines are drawn representing the volumes well above and well below the transition, the difference between the two straight lines at the inversion point may be taken as the bulk, or aggregate, volume change. Using $dT/dP = 28.7 \times 10^{-3}$ deg/bar, $\Delta V_{bulk} = 5.96$ cc/kg, and T = 845° K, Adams obtained the value 4.2 cal/gm for the heat of transformation. This agrees remarkably well with the calorimetrically determined values.

Discussion of Gibson's results

An examination of Table 2 shows that the agreement in values is not too good, but there may be in fact no real basis for comparison since Keith and Tuttle have shown that not all samples of quartz have the same inversion temperature or the same heat effect. On the other hand, the differences in compressibilities of the two forms for different samples are probably negligible, and differences of one per cent in heat effect would result in only a 0.3×10^{-3} deg/bar difference in the rate of change of the inversion temperature.

From a consideration of the Clapeyron equation there is the suggestion that GIBSON'S [1928] curve may have the incorrect curvature. This suggestion is based on the assumptions that the difference in volume between the high and low forms diminishes and that the heat of inversion increases with the rise in inversion temperature with increasing pressure. It is seen by substituting these qualitative assumptions in the Clapeyron equation that the dT/dP will decrease. In other words, the curve will be concave towards the pressure axis. The assumptions are based on the experimentally determined character of the normal solid-to-liquid and solid-to-solid transitions. Thermodynamically there is no difference between a liquid and a solid transition and a transition between two solids.

In addition, if there are differences in quartz due to solid solution, as suggested by Tuttle, the inversion point would be further depressed at high pressure. Consider the freezing point lowering equation

$$dT/dn = -RT^2/\Delta H$$

where R is the gas constant and n is the mol fraction of an impurity in the solution. In this formula ΔH increases with temperature, but by an amount less than T^2, so that in general the lowering of the freezing point increases at high pressure. This can be applied to solid inversions if it is assumed that the foreign material enters more into the high form, the more open-structure form, than into the low form. The solid-to-solid inversion temperature would be depressed at high pressure if an impurity were present. According to this argument also, the curve should rise at a decreasing rate rather than an increasing rate as indicated by Gibson.

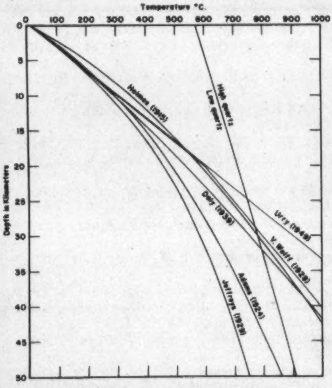

Fig. 5--Relation of experimentally determined high-low quartz curve to estimates of the geothermal gradient

Application to seismic problems

DALY [1928] suggested that one of the major discontinuities in the velocity of seismic waves at depth may be due to the change in elastic properties of quartz when it inverts from low to high quartz. If this change takes place universally at some particular depth in the Earth, then it can be assumed that the high-low quartz inversion curve intersects the geothermal gradient at this depth. The present opinions on the geothermal gradient in relation to the experimentally determined high-low quartz curve are given in Figure 5.

Of particular interest is the recent comment by GUTENBERG [1950] on the effect of the high-low quartz transition on the velocity of the seismic waves. He has focused attention not on the fact that the elastic constants of quartz increase abruptly above the inversion, but on the fact that the constants decrease to a strong minimum at the inversion [BIRCH and others, 1942, p. 70]. The minimum satisfies Gutenberg's requirements of a universal, low-velocity layer. He pointed out in a personal communication that in view of the nature of the minimum the rock containing the quartz could be at a temperature rather far from the actual transition point and still exhibit a low velocity. In this case the observed increase in velocity at greater depths could occur at the boundary between low "quartz more or less near the transition point and some other material (for example basalt)." The present measurements support the suggestion of GUTENBERG [1939] if his geothermal gradient, which is similar to that of von WOLFF [1928], is assumed. If, however, the geothermal gradient of ADAMS [1924] is assumed, it is unlikely that quartz would exist near its transition point except in local hot spots above approximately 60 km. Birch believes that the temperatures within the "normal" or "sea-level" crust are lower than has generally been supposed. He said, in a personal communication, "It is unlikely that the normal temperature-depth curve ever intersects or even comes within several hundred degrees of the α - β transition line." His reasons are to be given in a paper "The flow of heat in the Front Range, Colorado," which is to appear in a forthcoming issue of the Bulletin of the Geological Society of America. The chief objection to the speculations of DALY [1928] and GUTENBERG [1950] is that at or near the depths at which the transition might occur the rocks now thought to exist there are either very low in quartz or quartz-free.

Acknowledgments

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THE BEHAVIOR OF WATER DROPS AT TERMINAL VELOCITY IN AIR

Duncan C. Blanchard

Abstract--An insight into the behavior of large raindrops has been obtained by studying drops of water freely suspended in a vertical air stream. The wind tunnel employed is described. The stroboscopic pictures taken of the waterdrops show that extreme periodic deformations occur on drops of more than five millimeters diameter. The behavior of drops before and after collision was observed. Drops which come into a region within six centimeters above another drop usually begin to fall in an ever tightening spiral until collision takes place. The bombardment of large drops with a spray of small droplets showed that not all the small droplets coalesced with the large drops. Some of the smaller droplets would roll across the under surface of the large drop exhibiting a "bounce-off" effect. The breakup of a large waterdrop is easily brought about by imparting a sudden upward acceleration to the air through which it falls. On the other hand, a downward acceleration of the air is relatively ineffectual in causing breakup. The influence of the periodic deformation in causing breakup can be demonstrated by actually pumping air into a drop until the air bubble constitutes as much as 30 per cent of the drop. Such air-bubble drops show little or no deformation and will thus remain intact even when subjected to extremely turbulent air.

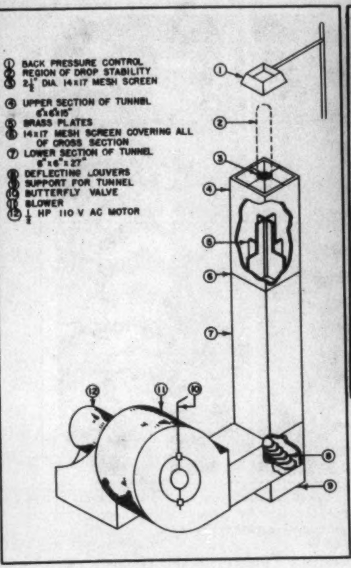
Introduction--Since the early investigations by LENARD [1904], very little work has been carried out on the subject of falling water drops. More recent work by LAWS [1941] established quite accurately the terminal velocity of water drops with the aid of photography. GUNN and KINZER [1949] determined terminal velocities by an electronic method. While Laws, and Gunn and Kinzer obtained excellent data on water drop terminal velocities, no attempt was made to study the mechanism of breakup. On the other hand, Lenard, whose determinations of water drop terminal velocities were apparently in error, experimentally established values for the maximum size of water drops and discussed their behavior at these sizes. However, as these observations were based on a time interval of a second or two, and no data were available on deformation at various sizes, the work reported in this paper was undertaken. The approach used by Lenard, that of suspending water drops in an air stream so as to be motionless with respect to an observer, seemed to be most feasible. However, the tunnel design was changed so that water drops could be made to float in the air stream for a much longer period of time.

The design of the wind tunnel--After much experimentation, the design of the wind tunnel shown in Figure 1 was found to be well suited for the purpose. The orifice measures five inches square. The critical components of the tunnel are the 14 by 17 mesh screens and the two crossed plates. The plates were used to provide a drag and thus lowering of velocity to the central part of the air stream. The importance of the screens lies in the fact that without them, the lowering of the velocity and the turbulence within are difficult to control. The wire mesh screens tend to retard a high velocity air stream to a much greater degree than a low velocity stream, and thus act as an equilizer. In other words, the air tends to emerge from all sections of the screens at approximately the same velocity.

The two and one-half-inch diameter screen in the center of the orifice serves not only to produce a minimum in the horizontal velocity distribution, but also a minimum in the vertical velocity distribution of the central axis of the air stream. The rectangular control device shown in Figure 1 exerts a back pressure on the air stream. Without the rectangular section, the drops would be accelerated upward.

The water drops were placed within the air stream by means of a medicine dropper, as shown in Figure 2. By calibrating the dropper, one could easily determine the amount of water and thus the diameter of the drop. By lowering the rate of air flow as a suspended drop evaporates, a large drop may be supported in the air stream until it has decreased in size such that the necessary reduction of air velocity for suspension cannot be smoothly obtained. In such a manner, large drops have been suspended for 40 min.

Photographic study of suspended drops--Stroboscopic photographs were taken in an attempt to determine the deformation, type of oscillation, mechanics of breakup, and other physical characteristics of falling water drops. To prevent serious overlapping of the images, the drop was allowed


① BACK PRESSURE CONTROL
② REGION OF DROP STABILITY
③ 2½" DIA. 14x17 MESH SCREEN
④ UPPER SECTION OF TUNNEL 6"x6"x15"
⑤ BRASS PLATES
⑥ 14x17 MESH SCREEN COVERING ALL OF CROSS SECTION
⑦ LOWER SECTION OF TUNNEL 6"x6"x27"
⑧ DEFLECTING LOUVERS
⑨ SUPPORT FOR TUNNEL
⑩ BUTTERFLY VALVE
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⑫ ½ HP 110 V AC MOTOR
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Fig. 1--The wind tunnel

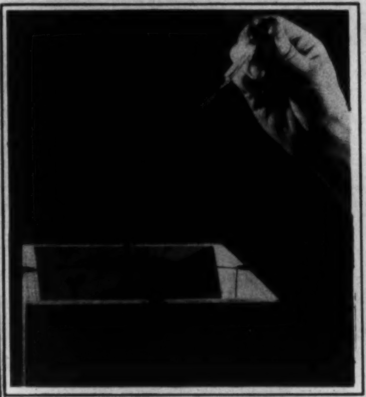

Fig. 2--Injecting water drops into the air stream by means of an eye dropper

to rise slowly past the field of view of the camera. Small amounts of silver chloride (about one part in 3×10^5) added to the water gave it a milky appearance without appreciably changing the surface tension; in this way the water drops were more easily photographed, than in their transparent state.

Over 70 stroboscopic pictures were taken of drops of various sizes. Some of the pictures brought out the type of oscillation and deformation which occurs, while others showed very clearly some mechanisms of water drop breakup. In each case the drop size was from five to ten millimeters, since smaller drops are stable in a constant velocity air stream and thus have no tendency to disintegrate.

Figure 3a shows a drop of 8.8 mm (spherical diameter) rising slowly in the air stream. The frequency of the stroboscopic light was 80 flashes/sec. Far from being tear-shaped, [EDGERTON and KILLIAN, 1939; LENARD, 1904; SPILHAUS, 1948], the drop is relatively flat and undergoes a periodic deformation. This type of deformation is quite unlike that of a small drop which often oscillates between the limits of a prolate and oblate spheroid.

There are two types of deformation, either of which will produce images like that in the picture. In the first type the drop is deformed by the air stream to a rigid ellipsoid with the major axis horizontal. It rotates on its vertical minor axis., As the drop rotates into full view, its maximum dimension along the major axis is seen. Continued rotation through another 90° will show a cross section of the drop through its minor axis. With such a mechanism in operation, the images shown between any two maxima or minima would depict an ellipsoidal shaped drop rotating through 180°.

The second type of deformation yielding the same images consists of a periodic oscillation which would cause the drop to oscillate between ellipsoidal shapes with the alternating major axes 90° apart in the horizontal plane. For example, if we assume an elliptical drop, the surface tension will tend to draw the drop into a spherical shape. The momentum of the process carries the contraction of the major axis beyond its equilibrium stage, and the minor axis is transformed into the major axis of an identical ellipsoidal drop at right angles to the original and in the same horizontal plane.

Both types of deformation have been observed, not only in the wind tunnel, but also during the

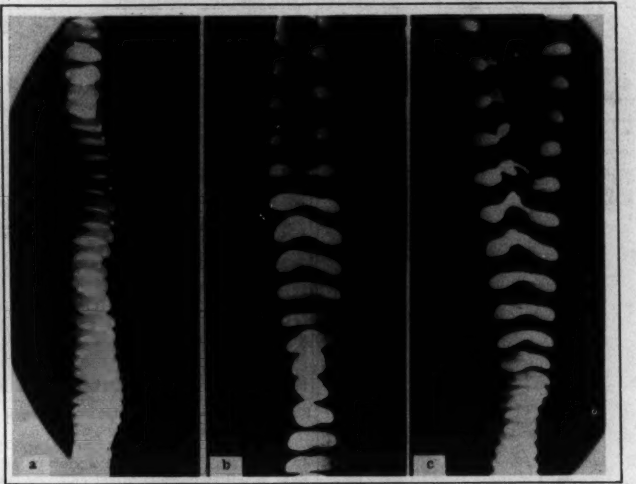

Fig. 3--Stroboscopic pictures of water drops; (a) 8.8 mm (spherical diameter), stroboscope frequency 80/sec; (b) 8 mm (spherical diameter), stroboscope frequency 90/sec; (c) 9.4 mm (spherical diameter), stroboscope frequency 70/sec

free fall of drops in the open air. Figure 3b illustrates the manner in which drops break up in a constant velocity air stream. The drop size was eight millimeters and the stroboscopic frequency was 90 flashes/sec. (Here and also in Figure 3c, the drop was rising in the air stream.) Note the extreme flattening of the drop and the appearance of the narrow neck of water shown in the uppermost image. This is characteristic of all drops undergoing disintegration in this manner. A similar type of drop breakup is shown in Figure 3c (drop diameter of 9.4 mm, stroboscope at 70 flashes/sec), except that here the evolution of the narrow neck into three separate similar smaller droplets is evident. This type of breakup can also be observed by allowing drops of sufficient size to fall from a height which will allow them to reach their terminal velocity.

The breakup that occurs as a result of momentarily interrupting the air flow is shown in Figure 4. (This is discussed later in the paper.) Here the drop diameter was 8.6 mm, and the stroboscopic frequency was 90 flashes/sec. In the background of this picture, the drop is seen rising slowly in the air stream. At a point above the picture, the air flow was interrupted for about 0.1 second. During this time, the drop began to fall. The drop has rotated nearly 90° on its horizontal axis and fallen with a lateral displacement. As the air stream again struck the drop, extreme flattening occurred which caused a typical shock-breakup, resulting in some twenty drops of various sizes. A majority of the fragments of the breakup were about one millimeter in diameter. In view of the turbulence encountered by raindrops in cumulonimbus clouds, this type of breakup may play an important part in the development of chain reaction [LANGMUIR, 1948] in setting off precipitation.

The measurements of drop deformation are a function of the spherical drop diameter. The graph of Figure 5 illustrates the drop deformation on drops > 5.5 mm. The data were obtained by analyzing the photographic records of drops of known size. The major and minor axes refer to the two normal axes of the drop in the horizontal plane. Their lengths are the greatest and least widths, respectively, of the drop images. It is interesting to note that the deformation increases rapidly with drop size so that on a nine millimeter diameter drop one would find a major axis of approximately 17 mm.

The growth of water drops--The growth of water drops within a cloud and their behavior during

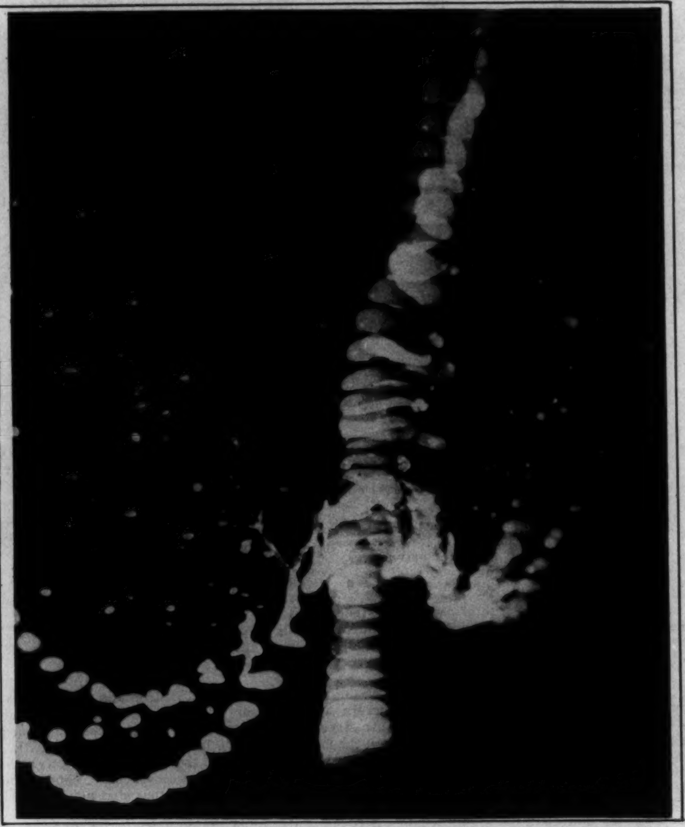

Fig. 4--Disintegration of a water drop by induced turbulence in air stream; drop diameter 8.6 mm, stroboscope frequency 90/sec

fall is still incompletely understood. LANGMUIR [1948] computed theoretically the rate of growth of small droplets by collision in a cloud of known liquid water content, while LENARD [1904] and WEISNER [1895] deduced from experiments that water drops $>$ 5.5 mm are unstable and can therefore exist no longer than a few seconds, and that in no case would their diameters exceed about seven millimeters.

The wind tunnel experiments have shown that under certain conditions, the presence of several water drops in close proximity will cause an apparent increase in terminal velocity of those on the lee of others, and result in their collision [BLANCHARD, 1948, 1949]. This effect was often noticed when two water drops were suspended in the wind tunnel, one above the other. If the upper drop should come within about seven centimeters of the lower drop, its partial protection from the

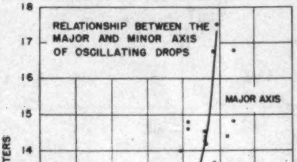

Fig. 5--A measure of the deformation of a water drop at terminal velocity as a function of the sperhical diameter

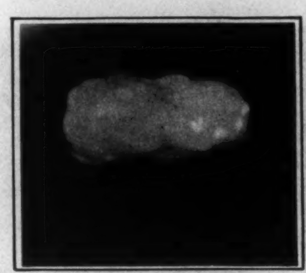

Fig. 6--The collisions of small droplets with a large drop at terminal velocity (although the size of the large drop was not obtained, it was estimated to be approximately eight millimeters spherical diameter); note the surface irregularities of the large drop produced by the collision

supporting air stream will bring about an increase in its velocity. Then, the upper drop will begin to fall toward the lower drop in an ever tightening spiral path ending in collision. This interaction between water drops greatly depends on their relative sizes. The effect is particularly striking when the upper drops are much smaller than the lower ones.

At present, no statement can be made regarding the frequency of this type of collision process in modifying the size of raindrops, since turbulence which was purposely suppressed in these experiments, enters the picture of raindrops falling through the free air. Nevertheless, this mutual interaction of falling drops may well have to be considered in computing the possible collision frequency.

Another interesting drop behavior was observed when a large water drop was subjected to a stream of smaller droplets. The small droplets (approximately 3/4 mm) were produced by forcing water through a capillary tube into the air stream several centimeters below the suspended large drops. The collisions thus occurred on the underside of the large drop (see Fig. 6). It might be expected at first that each small droplet would merge with the larger drop upon collision. While in most cases coalescence took place instantly, there were some in which the small droplets would roll or slide across the under surface of the large drop exhibiting what may be called a "bounce off" effect. Possibly this behavior is caused by an electrostatic charge which may be created at the source of the small droplets [NOLAN, 1914] or by the polarization of the water drop surface [SONDERS, ENRIGHT, and WEYL, 1949]. Some of the small droplets first bounce free from the large drop but, on entering its wake, will fall back into it and coalesce.

Water drop breakup--During a storm the size and distribution of the raindrops that strike the ground usually varies over a wide range [BENTLEY, 1904; BLANCHARD, 1949; LAWS and PARSONS, 1943], with the largest drops rarely exceeding six millimeters. Since it is relatively easy to suspend stable water drops in the wind tunnel as large as nine millimeters, (nearly three and one-half times the volume of a six millimeter diameter drop) it is evident that certain processes in the atmosphere must prevent the formation of raindrops of such large size.

According to the present study, one of the processes involved in limiting the growth of raindrops is the collision of large drops. The most important factor, however, appears to be the extreme sensitivity of large drops to turbulence. This sensitivity is strikingly demonstrated by passing one's hand swiftly across the air stream below a suspended drop (see Fig. 4). The drop will instantly shatter into many small fragments. It was undoubtedly the result of turbulence of the air that led LENARD [1904] to the conclusion that drops > 5.5 mm are unstable. A sudden increase of the air speed of about six per cent often suffices to cause drops ≧ eight millimeters to disintegrate.

Although any sudden change in the velocity of the air stream will affect drop stability, the drop behavior is radically different depending on whether the velocity is suddenly increased or decreased. A sudden increase in the air speed, analogous to a sudden updraft in the atmosphere, will subject the drop to increased pressures and consequently increased deformation [SPILHAUS, 1948] which may result in disintegration. On the other hand, a sudden decrease in the air speed, which corresponds to a downdraft, will not cause disintegration. This is due to the fact that then the pressure differences acting around the drop are decreased and the drop tends to assume the shape corresponding to the least free surface energy and maximum stability, that of a sphere. This behavior of water drops under suddenly decreased air speeds can be utilized to capture the drop, for example, in a flour-filled container, for weighing or other purposes [BENTLEY, 1904; BLANCHARD, 1949; LAWS and PARSONS, 1943].

The turbulence-induced disintegration raises the question as to the role played by the periodic deformation in this process. It was found that air could be pumped into suspended water drops, and that the presence of an air bubble effectively eliminated the natural oscillations of the drop. These bubble drops are produced with an eye dropper containing only enough water for the desired drop size. After the water has been forced out of the dropper, air can be injected into the drop. The oblate shaped bubble, which will bulge the upper part of the drop, may occupy as much as 30 per cent of the total volume (see Fig. 7).

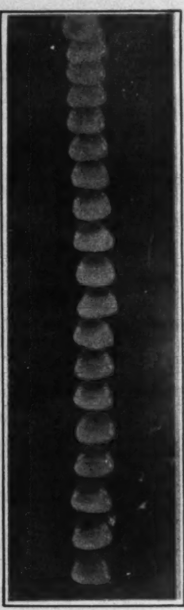

Fig. 7--A large water drop (at terminal velocity) which contains an air bubble

The remarkable property of such a bubble drop is that it is nearly indestructable when subjected to the interrupted air flow that caused breakup in ordinary drops of the same size. Turbulence merely causes the bubble drop to bounce up and down. Also on collision with other drops these stable drops lead to coalescence more often than to disintegration.

The behavior of the bubble drop seems to indicate that the disintegration of large drops is attributable to the drop oscillation. For large drops, the oscillation has a frequency of 24/sec or lower, decreasing with increasing drop size [BLANCHARD, 1948]. Whereas, in nonturbulent air, the natural drop oscillations are inconsequential regarding the persistance of the drops, any added stress, such as produced by turbulence or collision with other drops, will, in conjunction with the oscillations, tend to deform the drop beyond the form-restoring capacity of the surface tension.

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DEVELOPMENT AND UTILIZATION OF CONSTANT-LEVEL BALLOONS

W. D. Murray, C. S. Schneider, and J. R. Smith

Abstract--Controls have been developed to keep plastic nonextensible balloons at selected pressure levels in the troposphere and low stratosphere for long periods of time. These controlled balloon systems have also been used to hold instruments at constant levels. Tests have been made to check dynamic theory by plotting long period balloon trajectories at constant pressure altitude. Altitude, load limits, flight duration, and constancy are discussed, and present and future applications are considered.

Introduction--The development of equipment to study the properties of the free atmosphere has progressed steadily with the growth of the concept of "three dimensional weather." Aircraft, sounding balloons, rockets and even kites have been used as tools to sample the atmosphere, each vehicle with individual characteristics such as altitude range, load limit, and rate of rise. Appropriate sensing elements and recording or telemetering equipment have been designed for use with each type of vehicle.

To this list of tools may be added the plastic nonextensible balloon, now being produced in several sizes, each size with different load and altitude limits. Balloons of this type may be supplied with relatively simple mechanical and electrical controls which will cause them to remain at a given preselected level in the atmosphere for any desired period of time up to 48 hr. There are two special advantages which such a floating balloon has over other vehicles to carry meteorological sensors into the atmosphere up to 120,000 ft. These are: (1) The sensing instruments do not need to respond quickly as is the case with rockets and rapid-rising meteorological balloons. These vehicles rise and then fall rapidly without ever giving the sensing equipment a long enough time to come into equilibrium with the surrounding air at any given level. Admittedly, this can be overcome and has for the most part proven to be no barrier. However, simpler instruments with slower response are generally less costly and in many cases more accurate. (2) Assuming that the sensing equipment is able to correctly evaluate some quality of the physical state of a given section of the atmosphere, there remains the question of representativeness of the observation. With rapid-rising apparatus the experimenter gets only one instantaneous reading at the significant level, while with the controlled-altitude balloon a study may be extended for many hours, short-term variations of the variable at one level can be clearly seen and a statistical survey of the variable obtained.

The present system of control--Since November 1946, the Research Division of the College of Engineering of New York University has been under contract with the Geophysical Directorate of the Air Force Cambridge Research Laboratories through Watson Laboratories, Air Materiel Command, to develop and test constant-level balloon control systems. One system has now been in use for several months and has given very satisfactory performance. This system consists of a plastic nonextensible balloon using helium as a lifting gas and provided with an open appendix through which gas may be valved when the balloon becomes full. The cell is only partially inflated at the ground, and the lifting gas expands while the balloon is rising.

The balloon system can be made to float at any preselected level in the atmosphere by adjustment of the total load of the system. This may be seen from the basic equation for floating level of the balloon

$$V(d_a - d_g) = L$$

where V = balloon volume, d_a and d_g are densities of the air and lifting gas, and L is the total lift of the system. Here, the volume is fixed, as is the relationship between the density of the free air and the lifting gas. Thus for a fixed volume balloon, floating altitude is a function only of the total weight of the balloon system and the temperautre (or density) distribution of the atmosphere.

As lifting gas is lost by leakage and diffusion, the balloon tends to become unbalanced and descend. To maintain altitude constancy, the load is diminished by dropping ballast at the same rate at which lift is lost.

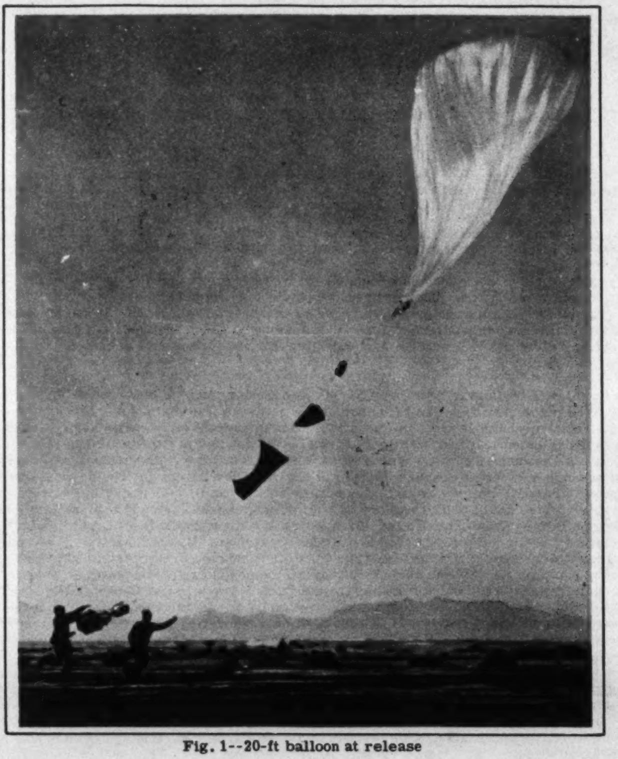

Fig. 1--20-ft balloon at release

Balloons used--Polyethylene is the plastic from which these balloons are made. Very thin sheets of this film are shaped into gores and sealed into a teardrop shape. The use of this particular plastic represents a compromise based on the consideration of porosity, permeability, tensile strength, low temperature properties and ease of fabrication of polyethylene as compared with other plastic materials. Figure 1 shows a 20-ft polyethylene balloon as it is launched with its control equipment.

When a plastic balloon is inflated with enough gas to make it rise, it will become full at some point below the maximum or floating altitude. To go to the floating level the balloon must be provided with an escape valve so that gas can be released. Without such a vent, the balloon will be ruptured as the gas expands.

Once in a floating condition, the balloon system is stable with respect to upward motion but in neutral equilibrium with respect to downward motion. This means that the balloon will resist displacement upward and will valve more gas to prevent rupture if upward displacement occurs (as by updrafts). When pushed downward, however, there is no restoring force since the volume will decrease (the balloon collapses), and the decrease in volume just balances the increase in buoyancy

Table 1--Load versus altitude for various balloon sizes

Balloon diameter	Load on balloon	Floating altitude
	lb	ft
20	100	30,000
	50	42,000
	10	65,000
30	150	43,000
	75	55,000
	10	85,000
70	300	85,000
	150	95,000
	25	110,000

caused by the greater density of the air at lower elevations. The same neutral equilibrium is the state of freely expanding balloons which are floating.

When the fixed-volume polyethylene balloon is flown with no controls, the floating altitude is maintained for two to six hours, after which time an accelerating descent finally becomes noticeable. Altitude ranges and load limits for various sizes of balloons are included in Table 1.

Use of ballast--To maintain a constant altitude it is necessary to compensate for the loss of lift occasioned by leakage or diffusion of the lifting gas and to make up for changes in the buoyancy which result from changes of the superheating of the gas. These latter changes in buoyancy occur at sunrise and sunset and are due to the radiation effect of the Sun on the balloon film. For example, at 40,000 ft during daylight hours, the lifting gas is approximately 8° C warmer than the free air if the balloon is floating. After sunset the lifting gas cools until it is the same temperature or 2° C lower than the free air.

Controlled ballast dropping is the system of compensation which has been found to be most satisfactory. A liquid ballast with a low freezing point has been used rather than sand ballast, since sand is difficult to control in minute amounts and will freeze in lumps if it picks up moisture either before or during the flight. Aircraft compass fluid, a kerosene-type petroleum derivative, has been used successfully.

Mechanical altitude control--The control of ballast flow has been accomplished by the use of an aneroid unit set to permit flow whenever the balloon system descends to a preselected pressure level. When this mechanical control is in operation, the balloon will rise with ballast discharge until the floating level is reached and the aneroid cell cuts off the ballast flow. By proper calibration of the flow rate and response of the control, it has been possible to minimize the hunting of the system. An exaggerated control action is shown in the height-time ballast curve of Figure 2.

The mechanical control unit itself consists of a standard temperature-compensated radiosonde aneroid unit with the pen arm riding on a special commutator bar. This commutator bar is divided into two segments, an insulator at the high altitude end and a conductor at the low altitude end. The aneroid pen arm is held on a shelf above the commutator during launching and for the first part of the initial rise. When it falls off the shelf an electrical circuit is closed through a relay-operated valve which is set in the ballast line. Ballast flow continues until the balloon rises above the conducting segment and stops when the pen rests on the insulator. Each time the balloon descends to the point at which the circuit is completed, ballast will be dropped. A schematic

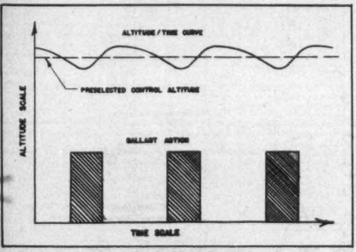

Fig. 2--Exaggerated altitude-time curve showing ballast action

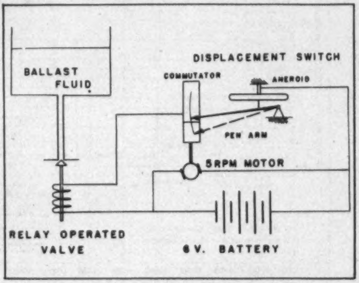

Fig. 3--Ballast control circuit

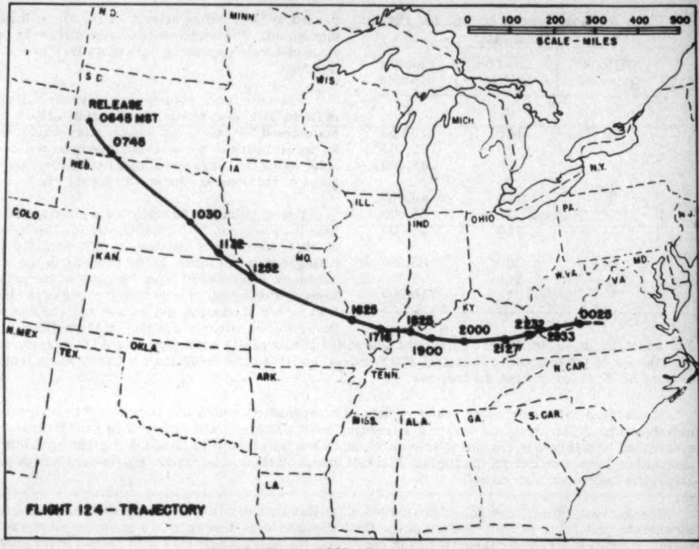
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Fig. 4--Typical 200 mb trajectory study

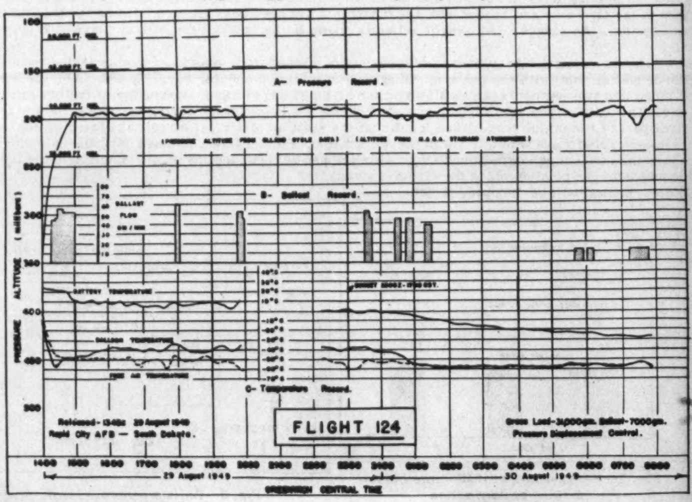

Fig. 5--Typical pressure-ballast-temperature/time plot diagram of this control is seen in Figure 3.

To minimize friction and to increase the sensitivity of this control, the commutator is made to rotate by an electric motor. With this system, recent flights consistently have been held to within 500 ft of a preselected floating level for many hours. During shorter periods an altitude constancy of 200 to 300 ft has been maintained.

Utilization of the balloon as an indicator of air flow--By mechanically controlling the altitude of a plastic balloon and my making frequent checks on its position, it is possible to study the motion of air along the surface of control. The simplest system is the mechanical pressure control just described, and many flights have been made with it.

It is possible, however, to control the vertical motion of a plastic balloon by other mechanical systems which will keep the balloon on a surface of constant density or some other meteorological variable which is not discontinuous.

An extensive program of determining air trajectories with a balloon on a constant-pressure surface has been sponsored by the Geophysical Research Directorate of the Air Force Cambridge Research Laboratories. The purpose of this series of tests was to obtain data to be compared with the geostrophic wind at 200 mb as derived from upper-air soundings. Figure 4 shows a typical balloon trajectory made during this study. The trajectory is shown as a solid line with Mountain Standard Time indicated next to specific points.

To position the balloon it was necessary to follow the flight path with aircraft, using a balloon-borne transmitter as a radio beacon on which the aircraft radio compass could "home in." Two planes were used in order to extend the trajectory study to a significant length.

While in the air the balloon system telemeters information regarding pressure, altitude, ballast requirements and temperatures to receiving stations. The light-weight amplitude modulated transmitter used (designed by Leon Hillman of the Research Division, College of Engineering, New York University) is capable of transmitting readable information up to 400 mi from a balloon at 40,000 ft to the ground, but for the trajectory study a recorder was mounted in each positioning aircraft and no network of ground receiving stations was employed.

The Olland or interval system was used to modulate the radio signal. In addition to pressure and free air temperature, the flow of ballast and the temperature of both the gas and the transmitter battery pack were given as a check on the performance of the system. White-coated ceramic thermistors were used to measure temperature and transmit the information as a function of modulation frequency of the transmitter. Ballast flow was measured by use of a siphon instrument developed specifically for constant-level flights. Information was transmitted through a radio receiver to a Brush recording oscilloscope. A typical Pressure-Ballast-Temperature/Time Curve is shown as Figure 5.

The results of the trajectory study are not yet ready for publication, but a series of 24 flights has been completed and should provide sufficient data to make an interesting comparison of the observed flow with that predicted by dynamic theory.

Utilization of the balloon as a vehicle--Plastic controlled-altitude balloons have been used to carry instruments to a desired level and maintain them for several hours on numerous occasions. The use of such balloons by Navy-sponsored groups to study cosmic rays is well known.

A special control system has been used in one series of New York University flights with the aim of causing the balloon to float first at one level for an hour or more and then move to a higher level for a comparison study. Here the feature of comparing two samples taken on the same day with a single set of equipment is outstanding. A single set of counters was used at both levels with no intermediate calibration or handling required. This series of flights was sponsored by the Air Force in study of high energy neutron intensity as a function of altitude. An interval system was used to telemeter the data, and by superposition and programming three sets of data were collected on one recording channel.

Other uses suggested for controlled-altitude balloons--From the foregoing discussion of the properties of this new meteorological tool, it will follow that its special properties recommend it for use in a large number of studies. These possible uses are divided into two classes--the studies of air motion, and the use of the balloon as a vehicle to carry atmospheric instruments. Trajectory-type studies might include (a) studies of dispersion or large-scale diffusion in the atmosphere by use of several constant altitude balloons placed simultaneously, at one given altitude; (b) studies of stratospheric circulation (speed and direction can be obtained up to 100,000 ft with balloons now in production); (c) studies of deformation of horizontal flow over a barrier; (d) studies of the delineation of various thermodynamic surfaces on which suitable controls could be applied (such as surfaces of constant potential temperature, constant density or constant temperature); and (e) tropospheric wind patterns at various levels and latitudes. (Study of such items as hurricane build-up and equatorial air motion have been suggested.)

Within the vehicular grouping, the following applications suggest themselves: (a) Air sampling either at one or more levels by use of actual air collection techniques or by use of sensing instrumentation. Samples could be taken at several times at one level to show successive concentrations, or continuous records may be obtained by use of instruments that will continuously sample and transmit information relative to some atmospheric variable. Flights might be made to determine chemical composition of the air; spores and bacteria in the atmosphere; ozone concentration, (the possible existence of ozone clouds and some of the theories of ozone transport might be checked by the use of constant-level balloons); and solar radiation and cosmic ray intensity. (b) High-altitude test of equipment designed for use on rockets or high-level aircraft. (The 70-ft balloon will carry 200 lb to an altitude to 90,000 ft and maintain equipment at these levels for long periods of time.) (c) Use of a large balloon to carry and drop radiosondes over oceans and inaccessible areas. The feasibility of sending constant-altitude balloons over such long distances was recently demonstrated by the completion of two trans-Atlantic balloon flights. A routine trajectory flight was released from Holloman Air Force Base, New Mexico on March 2, 1950 and followed by aircraft into west Georgia where it was abandoned. On March 4 this balloon was discovered lying in a snow bank in Myrdal, Norway, having crossed nearly 5000 mi of ocean in addition to over 1200 mi of continent. This balloon remained afloat for 50 to 52 hr and carried a full load of equipment throughout the trip. Another flight, released on March 14, was followed to southwestern Virginia. It landed two days later in northeastern Algeria. Similar flights, released from the east coast and set to float at a level marked by high-velocity winds, should consitently be able to complete the transoceanic trips.

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FORCES EXERTED BY WAVES ON A SLOPING BOARD

W. S. Hamilton

Abstract--A piece of plywood was mounted on six strain-gage cells in a wave tank to determine wave forces on a mildly sloping plane. Wave heights upwind and downwind were measured to find its effectiveness as a stilling device. The measurements showed that the reactions of the supports did not exceed those that would be produced by a uniform hydrostatic loading equal to 0.8 of the wave height applied alternately upward and downward. A properly placed board reduced wave heights downwind to less than 60 per cent of the height upwind provided their length was not more than four times the board width measured parallel to the direction of wave propagation. Waves about as long as the board width were reduced as much as 90 per cent. A method of estimating wave loading is suggested.

Introduction--The inner harbor at Grant Park in the city of Chicago is about one-third mile wide and one mile long and is protected by artificial breakwaters. The harbor is used exclusively for small pleasure craft and is quite crowded. At present, most of the boats are moored at the bow to fixed anchors, leaving them free to swing with the wind. Since this scheme of mooring requires a good deal of space for each boat, it has been proposed to relieve the congestion by building a wharf with numerous slips perpendicular to it in which boats may be tied.

Because of the length of the harbor, waves are sometimes two to three feet high when the wind is SSE. It was felt that boats moored in slips practically against steel piling should be protected by some sort of wave breaker built as an integral part of the wharf. Such a wave breaker would be required to furnish comparatively quiet water on the landward side without setting up reflections that would seriously increase wave heights outside of the protected area. Moreover, the whole project would not be feasible if the breakwater added a proportionately large sum to the cost of the wharf and slips.

Since partially submerged sloping boards are very effective in stilling waves in towing tanks, the possibility of using slabs about 12 ft wide underneath the wharf was investigated. These slabs, made of steel, concrete, or wood, would form a continuous shelf with its high edge slightly above the usual water level and its lower edge about two feet below. Because the effect of such a shelf on waves was largely unknown and the forces required to support it also were not known, tests were run in the Northwestern University towing tank to determine (a) the increase in wave height, if any, on the windward side; (b) the ratio of the wave height on the downwind side to the height upwind; and (c) the reactions of the supports required to hold the shelf in place.

Description of equipment--The Northwestern towing tank is about 75 ft long and nine feet wide. It is equipped with a flapping-gate type of wave-maker. A piece of plywood two feet wide, one inch thick, and long enough to span the tank without touching either wall was used for the test shelf. It was supported by six pin-connected rods, three near each end, as shown in Figure 1. The rods were held at their outer end by clamps, which permitted the height and the slope of the board to be changed.

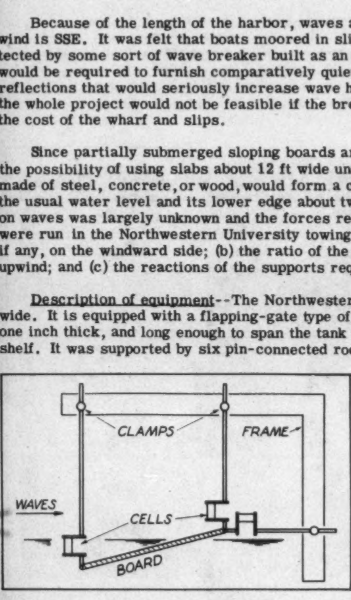

Fig. 1--Method of supporting board

Each rod was broken near the board by a specially constructed strain-gage cell, which acted as a short, eccentrically loaded column. As shown in Figure 2, inside each cell were two SR-4 strain gages. Although both gages were active, one was used as a dummy and the other as the active gage in a standard Wheatstone bridge. Thus strains in the same direction due to temperature changes would not unbalance the bridge, but strains in opposite directions due to bending and compression would unbalance it. Amplifying and pen recording equipment

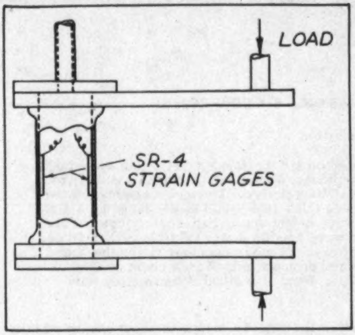

Fig. 2--Waterproof strain cell

manufactured by the Brush Development Company was used to make a record of the strains (and hence the forces exerted on the rods) when the waves acted on the board.

Figure 3 shows a close-up of two of the cells which suggests the method of calibrating the horizontal one. At the beginning of each set of test runs, ten-pound weights were either placed directly on the board or hung on the strings as shown in this picture, and the deflection of the pens in the recording equipment was adjusted to read a suitable number of lines of deflection.

Although the effect of the board on the waves was recorded in motion pictures, wave heights were measured 15 ft upwind from the board and eight feet downwind, using hook and point gages.

In order to gain a better understanding of the motion of the water particles near the board, slow motion movies of an analogous arrangement were made in a transparent flume. A mixture of white lead, oil turpentine, and carbon tetrachloride was adjusted to a specific gravity of 1.0, and small droplets of this mixture were scattered through the water in the flume. Waves were then generated and the motion of the droplets photographed.

Scope of the tests--About a hundred test runs were made in the towing tank, a number by no means sufficient to investigate all the possible positions of the board for a large variety of waves. Wave heights ranged from 0.1 to 0.6 ft, which would represent the region from 0.6 to 3.6 ft in the prototype. The shortest waves generated were 1.3 ft, and the longest, 20 ft. The slopes and elevations of the board are indicated in Table 1. Board elevation is defined as the distance measured upward from the still water surface to the top of the downwind edge of the board. This always was the higher edge.

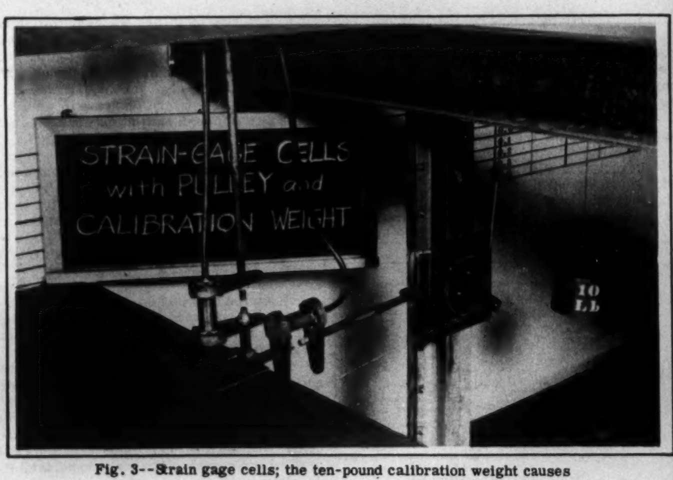

Fig. 3--Strain gage cells; the ten-pound calibration weight causes compression of the horizontal rod

Table 1--Board positions

Inclination	Elevations			
	ft			
$\sin^{-1}$ 0.15	. . .	0.15	0.00	-0.15
$\sin^{-1}$ 0.30	0.30	0.15	0.00	-0.15
$\sin^{-1}$ 0.60	0.30	. . .	0.00	-0.15

Results of the tests--The test results fall into two categories: first are those which show whether a sloping board would be a desirable breakwater and, if so, what the design reactions would be for certain waves. The second category includes whatever information may be helpful in understanding the action of the board, the motion of the water particles, and in estimating the total force that would be exerted on the board under chosen conditions. This latter category will be discussed in the following section.

The board influenced the wave pattern upwind because of reflections. Although it added no energy to the system, the board could be considered loosely as a secondary wave-maker which produced one or two minor pulses for each of the primary waves. As these secondary pulses traveled upwind, they increased the height of the primary waves at some points and decreased it at others. Had the reflections been of the same magnitude as the oncoming waves, a system of standing waves would have been produced, but this was not usually the case. In fact, when the inclination of the board was $\sin^{-1}$ 0.15 or $\sin^{-1}$ 0.30, the increase in height of the waves upwind was rarely more than ten or 20 per cent and sometimes was not noticeable at all. However, during a few test runs the height of the primary waves was more than doubled; for example, when the board was inclined at an angle $\sin^{-1}$ 0.15 and the higher edge was at the still water level, primary waves 0.4 ft high and six feet long gradually built up to a height of one foot. On another occasion waves 0.2 ft by eight feet increased to 0.55 ft upwind. These particular effects, of course, were partly dependent on the distance between the wave-maker and the board, because the secondary waves could travel all the way upwind to the wave-maker (about 40 ft) and alter the waves at the source.

For a harbor having no reflecting surface nearby in the upwind direction and no regular wave pattern, the result of reflections cannot be predicted from the present tests. The development of greatly augmented wave heights, however, seems less likely in the harbor than in the towing tank.

When the board was set at $\sin^{-1}$ 0.60, the effect was much like that of the usual solid vertical or sloping breakwater. The primary waves did not break but consistently were reflected, with a resulting height increase upwind of 50 to 100 per cent.

In the vicinity of the board, of course, the motion of the water depended on the elevation of the high edge. When the board was submerged, small waves could pass over it without breaking, and the larger ones broke or "tripped" just as the crest passed the high edge. Moreover, a strong vertical eddy was created that would carry floating objects downwind with a jerky speed of up to one foot per second.

On the other hand, when the board was set with the after edge somewhat above the still water level, a wave would break before the crest reached the upwind edge. In this case, the flow of water off the board in the upwind direction created a vertical eddy that would carry objects floating on the surface slowly upwind. When the board was set with the high edge in the water surface, both the upwind and downwind eddies were formed, but neither was very strong.

Within the limits of the wave heights tested (up to 0.6 ft), the ratio of the wave height downwind to the wave height upwind, h_2/h_1, was found to depend chiefly on the wave length and the board elevation. For example, long waves, which disturb the water to great depths, passed under the board with relatively little loss in energy. The wave height and the slope of the board exerted secondary influences. In Figure 4 is a plot of the ratio h_2/h_1 versus the ratio of wave length divided by the board width, ℓ/B. Note that h_1 was measured 15 ft upwind from the high edge of the board and that h_2 was measured eight feet downwind. For this particular figure, the downwind edge of the board was 0.15 ft below the still water level. Points are plotted for two values of the board inclination θ; the circles refer to $\sin \theta = 0.15$, while the crosses mark the points for which $\sin \theta$ is 0.30.

It is evident from Figure 4 that a submerged board was not very effective in reducing the wave heights downwind, the average reduction being about 20 per cent. Also for this particular setting, the effect of the board shows little dependence on the wave length. The scatter of the points for a given ℓ/B ratio is present because runs were made for wave heights of both 0.2 and 0.4 ft.

In Figure 5 the effect of a board set with the downwind edge at the still water level ($y = 0$) is

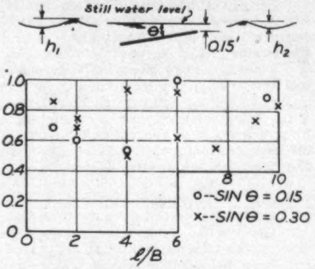

Fig. 4--Wave height ratios

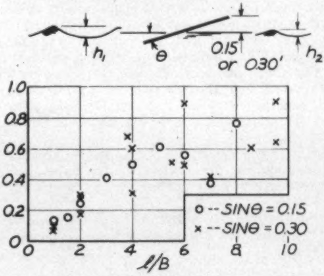

Fig. 6--Wave height ratios

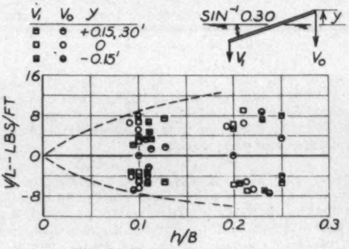

Fig. 8--Vertical reactions

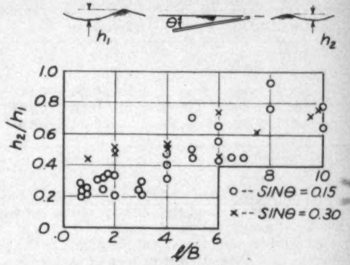

Fig. 5--Wave height ratios

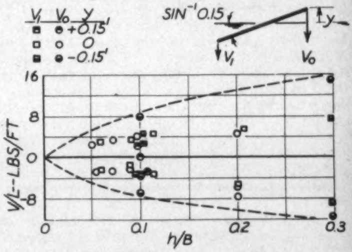

Fig. 7--Vertical reactions

shown. Here a direct relation between the effectiveness of the board and the wave length ratio is apparent. Moreover, the board with the smaller slope is more effective for the short waves.

Figure 6 shows a similar dependence of h_2/h_1 on ℓ/B when the downwind edge of the board is set above the still water level. (The elevation, y, was equal to 0.30 ft only for a few runs when θ was equal to $\sin^{-1} 0.30$). This figure shows that a slightly elevated board affords the best protection downwind for comparatively short waves. The reasons are, of course, that most of the short waves did not spill over the high edge and at the same time due to the concentration of energy near the surface, only a minor disturbance passed underneath.

Certain representative values of the reactions necessary to support the board are shown in Figures 7 and 8. In general, very short waves produced small reactions, and for the medium and long waves the data were not sufficiently complete to show any clear-cut relation between forces and wave lengths. Hence, in these figures the wave height divided by the width of the board h/B was chosen as the independent variable with the ratio V/L for the dependent variable. V_1 is the vertical reaction at the upwind edge of the board, V_0 the vertical reaction at the downwind edge, and L is the length of the board perpendicular to the paper. In the figures, points represented by circles are for V_0, and those represented by squares are for V_1. Moreover, as indicated in the legend, the reactions for an elevated board are plotted with the upper half of the square or circle black. Open squares or circles indicate that the downwind edge of the board was in the still water surface, while symbols with the lower half filled in indicate that the board was submerged. Note that the reactions are positive downwards; hence a positive value of V/L indicates that the water tends to lift the board.

Inspection of Figures 7 and 8 shows the following facts: (a) The upward force exerted by the waves on the board was usually equal to or more than the downward force. (b) The reaction at one edge of the board did not consistently exceed the reaction at the other. (c) The largest reactions occurred when the board was submerged, and the smallest, when the board was elevated. (e) The waves did not produce excessively large reactions.

With regard to the last point, it may be instructive to consider an example. Thus from Figure 7 we note that a wave 0.5 ft high ($h/B = 0.25$) would not be likely to cause a single reaction greater than 14 lb for a board two feet wide and one foot long perpendicular to the paper ($V/L = 14$). If this board were thought of as a 1/6 scale model of a shelf 12 ft wide, the corresponding prototype wave would be three feet high. The reaction per foot of length of shelf would be about 500 lb, and the sum of two reactions would not exceed 1000 lb. This is equivalent to a loading of about 85 lb/sq ft. (Note that in the two-dimensional case, the force-scale ratio is equal to the square of the length-scale ratio, since the dimension perpendicular to the paper is the same in both model and prototype.)

A plot of the horizontal reactions has not been prepared. The data were checked as follows, however, to see whether or not these reactions were consistent with the vertical ones. Neglecting skin friction and edge effects (that is, assuming the force exerted by the waves to be normal to the board), it is apparent that the horizontal reaction should not exceed the sum of the vertical reactions times the tangent of θ. Except for a few dubious measurements, this was the case.

A method of estimating the force on the board--From an analytical and practical standpoint, it is desirable to devise a means of computing the force exerted by waves on a sloping board. Even if the local disturbance near the board were ignored, however, the possibility of obtaining a potential function (from which forces might be computed) to fit the boundary conditions seems remote. Hence the writer chose to make certain simple assumptions and calculations to find forces that should equal or exceed the actual wave forces. The procedure and a comparison of the results with test results for a special case follow.

From the force charts, moving pictures, and notes, the wave positions causing maximum upward and downward forces on the board are known to be about as shown in Figure 9. (The waves and particle velocities are drawn as if uninfluenced by the board.) Noteworthy is the fact that the largest upward force occurs when the water underneath is trying unsuccessfully to rise through the board and fill the space above it. The fact that the rising mass must change direction and flow around the windward edge explains why even a horizontal board will "starve" the rising side of the wave, causing it to steepen and break. Moreover, the photographs show that regular orbital wave motion occurs a short distance upwind from the leading edge (presumably accompanied by a corresponding pressure pattern), but that at the downwind edge the orbits decrease in size and become distorted.

The foregoing facts suggest dividing the vertical force exerted by the waves on the board into two parts, first, the upward force caused by the pressure underneath the board and second, the downward force due to the weight of the water above the board. The facts also suggest that an estimate of each part may be based on the following assumptions (see Fig. 10): (a) motion in two dimensions; (b) fluid without viscosity; (c) board imagined to be shifted to the horizontal position A-A at $z = h/2$; (d) a sinusoidal wave form producing a pressure distribution at section (1) of $p_1 = w[z + (h/2)\cos(2\pi t/T)]$; (e) $p_0 = wz$ = constant at a fixed depth; (f) a volume of water above A-A that varies between zero and hB (per foot of length perpendicular to the paper), producing a downward force

$$F_d = whB \sin^2 \pi (t/T + 1/4)$$

Here p is the pressure, lb/sq ft, at a depth z ft below the still water level, T is the wave period and t is time, both in seconds. Time is equal to zero when the wave crest is at (1). (Assumption (d) of hydrostatic pressure distribution will tend to make computed upward forces too large. See, for example, FOLSOM [1947, 1949] who points out the difference between the pressure variation at depth z and the product wh.) Assumptions (a) through (e) lead to a horizontal oscillation of the mass M under the unbalanced pressure $p_1 - p_0 = (wh/2)\cos(2\pi t/T)$. Moreover, the unbalanced pressure in a horizontal lamina will vary uniformly as indicated in the sketch, since

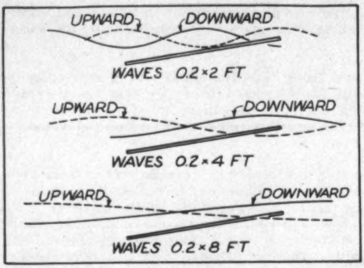

Fig. 9--Wave positions for maximum loads

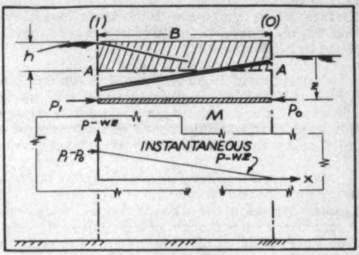

Fig. 10--Notation for estimating wave force

$$\partial p/\partial x = -wa_x/g$$

and the horizontal acceleration a_x is a function of t only. Thus the force acting upward on the board due to the pressure underneath will be $F_u = (p_1 + p_0)B/2$, where p_1 and p_0 are taken at $z = h/2$

$$F_u = wB\,[h/2 + (h/4) \cos (2\pi t/T)]$$

Assumption (f) is a purely arbitrary means of varying the amount of water above the board from zero, when the wave crest is 1/4 wave length to the left of (1), to a maximum value when the crest is 1/4 wave length to the right.

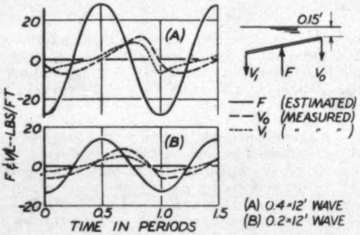

Fig. 11--Estimated and actual forces

The net force exerted by the wave in the upward direction is then

$$F = F_u - F_d$$

$$= wBh\,[1/2 + (1/4) \cos (2\pi t/T) - \sin^2 \pi (t/T + 1/4)] \text{ lb/ft of length}$$

The term in brackets is symmetrical about zero with maximum and minimum values of about ± 0.6, thus indicating that the maximum upward or downward force on the board would be equivalent to a uniformly distributed load of 0.6 wh lb/sq ft, that is, a hydrostatic load equal to 60 per cent of the wave height.

In Figure 11 are plotted the estimated wave force F and the measured reactions V_0 and V_1 for two waves that caused especially large reactions (reactions about on the envelope curve of Fig. 7). If the estimates were correct, addition of the ordinates of the dotted and dashed curves would give the continuous curves. Obviously the estimates are incorrect, but it is apparent that the instantaneous sum of the reactions does not exceed the peak estimated force.

If, however, the peak force F, being assumed uniformly distributed across the board, is divided by two to get either reaction, the result may be an underestimate. For example, in Plot B of Figure 11, half the peak value of F is seven pounds per foot, but the maximum reaction is nine pounds per foot. Hence it is necessary to change the equivalent hydrostatic loading from 60 to 80 per cent of the wave height to obtain a total force equal to twice the maximum reaction.

Concluding remarks--A shelf 12 ft wide having a slope of 0.15 would serve as an effective breakwater for waves up to three feet high and 50 ft long so long as the still water level remained at or slightly below the high edge of the shelf. Approaching waves would be altered by reflections, but their height would not usually be increased appreciably by the direct reflections from the shelf. No information is available on the effect of the shelf on waves approaching from the landward side, that is, waves that would contact the high edge first.

Appreciable surface currents would be generated on the downwind side of the shelf by waves breaking over it. Such currents might make it difficult to maneuver sailing craft into a mooring position close to the downwind side.

For the size of shelf and waves mentioned above the total forces exerted by the waves would not be large enough to make the structural design a difficult problem.

Acknowledgments--The author is indebted to J. W. Magill, who suggested the project, E. A. Beck, who built the equipment, to several students who ran tests and took moving pictures, and to Northwestern Technological Institute, which supplied the necessary funds.

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THE APPLICATION OF CONFORMAL TRANSFORMATIONS TO OCEAN WAVE REFRACTION PROBLEMS

Leon S. Pocinki

(This paper was accepted as partial fulfillment of the requirements for the degree of Master of Science in the Department of Meteorology, New York University)

Abstract--If the bottom contours are considered straight and parallel, and if the usual assumptions are made, a simple differential equation for the orthogonals can be derived from Snell's Law. Solutions to the equation are easily obtained. Conformal transformations may be applied to change the contours in the complex Z-plane into several different configurations in a complex W-plane. In each case an orthogonal in the Z-plane maps into a new orthogonal in the W-plane, and thus a solution to the problem of wave refraction over the contour system in the W-plane is obtained. An expression for K_d is then derived from the orthogonal pattern. Cases treated include a circular island, a reef and a bay with parabolic contours, and twin islands. The method indicates considerable future possibilities in different applications.

Introduction--This paper is an attempt to describe mathematically the orthogonals to ocean waves being refracted over particular bottom contour configurations. These solutions are desired as a test of theory in connection with future model studies. First an equation is derived for waves approaching a straight continuously sloping beach with parallel bottom contours. Then the straight contour lines are transformed conformally into several new systems, and the equation is transformed into one valid for each new configuration. The problem is considered in terms of non-dimensional quantities. Depth contours are indicated in terms of the ratio of the wave length at that depth, L, to the deep water wave length, L_0. Horizontal distances are completely arbitrary.

In the general case where the bottom contours are not straight and parallel, graphical methods of drawing the wave fronts or orthogonals [JOHNSON, O'BRIEN, and ISAACS, 1948] may be employed. ARTHUR [1946] has obtained solutions for the refraction of waves approaching certain circular islands and shoals. LOWELL [1949] has treated the problem in a more general mathematical fashion. He has shown that Snell's Law and the other results obtained in geometrical optics may be applied to ocean waves in shallow water under certain assumptions.

In the present treatment of the wave refraction problem the usual assumptions are made. They are: (1) The wave velocity at any point depends only upon the still water depth below the wave at that point and the deep water wave velocity. (2) The wave crest advances perpendicular to itself. (3) The wave energy between orthogonals is conservative. (4) The wave period is constant.

Snell's Law describes the refraction of a wave as it passes over a bottom contour marking a change of depth from d_1 to d_2. It is $C_1/C_2 = \sin\alpha_1/\sin\alpha_2$. Here C_1 is the wave speed at the depth d_1, α_1 is the angle between the wave crest and bottom contour at that depth, C_2 is the wave speed at the depth d_2, α_2 is the angle between the wave crest and bottom contour at that depth. It should be pointed out that α is also the angle between the orthogonal and the normal to the contour.

Snell's Law may be written as (1) which relates the wave speed and the angle between the wave crest and the bottom contour at any two depths.

$$C/C_0 = \sin\alpha/\sin\alpha_0 \qquad (1)$$

Usually C_0 and α_0 refer to the wave speed and angle in deep water. This equation is valid for any bottom contour configuration but is most easily applied to the particular case of straight, parallel contours.

The change of wave height due to refraction and shoaling is given by $H = K_d D H_0$. Here H_0 is the deep water wave height, H is the wave height at depth d, and D is a factor which accounts for the change in group velocity. K_d, which accounts for refraction, is defined by (2) where b_0 is the length of wave crest between two orthogonals in deep water and b is the length of wave crest between the same two orthogonals at depth d.

$$K_d = \sqrt{b_o/b} \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (2)$$

For the case of straight parallel bottom contours, the expression for K_d becomes $K_d = \sqrt{\cos \alpha_o / \cos \alpha}$ where α may be determined by $\alpha = \sin^{-1} (C/C_o \sin \alpha_o)$. [JOHNSON and others, 1948, pp. 1-4].

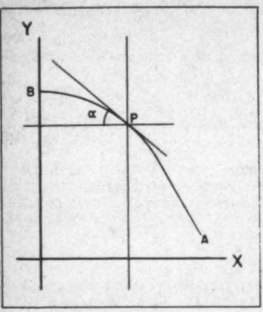

Fig. 1--Schematic representation of an orthogonal (AB) to a wave train approaching the straight beach with continuously sloping bottom

Straight beach--Consider a straight, continuously sloping beach with bottom contours parallel to the Y axis; α is the angle between the normal to the contour at an intersection P (see Fig. 1) and a tangent to the orthogonal at P. An orthogonal is then a smooth curve, indicated by AB in Figure 1; its slope is given by

$$\tan \alpha = dy/dx \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (3)$$

By the use of a few trigonometric identities, (1) may be written

$$\tan \alpha / \sqrt{\tan^2 \alpha + 1} = (C/C_o) \sin \alpha_o \ . \ . \ . \ . \ (4)$$

If the period of the wave is constant, then

$$L/L_o = C/C_o \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (5)$$

where L and L_o are the wave lengths where the wave speeds are C and C_o respectively [BEACH EROSION BOARD, 1948]. Substitution from (3) and (5) in (4) gives

$$dy = \left\{ \left[(L/L_o) \sin \alpha_o \right] / \sqrt{1 - (L/L_o)^2 \sin^2 \alpha_o} \right\} dx \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (6)$$

Eq. (6) is an ordinary differential equation for the orthogonals where L/L_o is an arbitrary function of x, which must be specified in any particular case. In particular, we shall examine the function given by

$$\left. \begin{aligned} L/L_o &= x \qquad 0 \leq x < 1 \\ &= 1 \qquad 1 \leq x < \infty \end{aligned} \right\} \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (7)$$

Thus the shore is the Y axis. Refraction occurs in the region $0 < x < 1$. In the region $x \geq 1$ the wave length L is equal to the deep water wave length L_o.

The function (7), then, implies a certain slope of the bottom. The value of the ratio L/L_o at any depth d is $L/L_o = \tanh (2\pi d/L)$ [BEACH EROSION BOARD, 1948]. Then, by (7), the depth at any point is given by

$$\left. \begin{aligned} d &= (xL_o/2\pi) \tanh^{-1} x \qquad && 0 \leq x < 1 \\ d &= \infty && 1 \leq x < \infty \end{aligned} \right\} \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (8)$$

These relations give the result that the depth in the region $x \geq 1$ is infinite. Refraction occurs for $x < 1$, that is, as soon as the depth becomes finite. Eq. (8) may be solved for any value of the depth (in terms of L_o) by successive approximation. For $d = 0.5 \ L_o$ the result is $x = 0.9964$. Thus, in this theoretical solution, the amount of refraction for depths in the range $0.5 \ L_o < d < \infty$ is very small. Indeed, in practice, it is customary to neglect the refraction effects for depths greater than one-half the deep water wave length. BIGELOW and EDMONDSON [1947], for example, discuss this approximation.

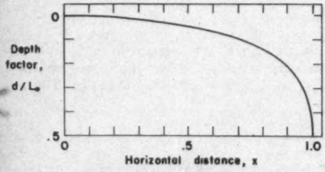

Fig. 2--Bottom profile for the straight beach problem

The depth profile is shown by a graph of the depth factor, d/L_o, in relation to the horizontal distance in Figure 2. For the reasons just mentioned the depth at x = 1 is approximated by $d = 0.5 \ L_o$ in this figure; but no such approximation is made elsewhere. The calculation of the refraction effects depends on the function for L/L_o; that is, refraction begins when the depth is less than infinite.

Upon substitution of (7) into (6), the differential equation becomes (9) which may be integrated to give (10).

$$dy = [x \sin \alpha_o / \sqrt{1 - x^2 \sin^2 \alpha_o}]dx \quad \text{(9)}$$

$$(y - m)^2 + x^2 = \csc^2 \alpha_o \quad \text{(10)}$$

Eq. (10) is the equation of a circle with center at (0, m) and radius = csc α_o. The value of the constant m is determined by the point of intersection of the straight line representing the orthogonal in deep water and the line x = 1. Several orthogonals are shown in Figure 3. These do not represent the refraction of a straight deep water wave crest; instead each orthogonal is drawn for a different value of the deep water wave angle α_o.

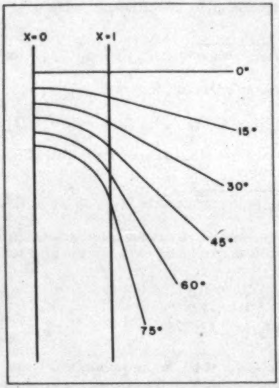

Fig. 3--Orthogonals given by the solution to the straight beach problem, Eq. (10), for various values of the deep-water wave angle α_o

It will be convenient for some of the work which follows to consider a simple variation of this configuration. If L/L_o is represented by (11) the refraction zone is the strip $1 \leq x \leq 2$ with the depth contours given by the lines x = constant. For a wave train moving from left to right refraction begins at the line x = 1, and the shore is represented by the line x = 2. Then an orthogonal is given by (12).

$$\left.\begin{aligned} L/L_o &= 2 - x \qquad & 1 < x \leq 2 \\ &= 1 & -\infty < x \leq 1 \end{aligned}\right\} \quad \text{(11)}$$

$$(y - \beta)^2 + (x - 2)^2 = \csc^2 \alpha_o \quad \text{(12)}$$

General considerations regarding the application of conformal transformations--Although the solution for the straight parallel contour problem has been obtained under very restricting assumptions, the introduction of conformal mapping allows it to be extended to many other bottom contour configurations. In the theory of the functions of a complex variable it is shown that an analytic function, w = f(z), transforms two intersecting curves, C_1 and C_2, in the Z-plane into two intersecting curves, S_1 and S_2, in the W-plane and preserves the angle between the curves at their point of intersection, if the point is not singular for the particular transformation. A proof of this theorem is given, for example, by PHILLIPS [1947]. This property of a conformal transformation is illustrated in Figure 4. These considerations and certain other properties have made conformal mapping a powerful tool in such fields as electrostatics and hydrodynamics. These applications are illustrated, for example, by JEANS [1948] and LAMB [1945].

The XY-plane may be represented by a complex Z-plane where the complex point is written as $z = x + iy$ in Cartesian coordinates and as $z = re^{i\theta} = r(\cos\theta + i\sin\theta)$ in polar coordinates. Points in the W-plane are denoted by $w = u + iv = \rho e^{i\phi}$. These coordinates are illustrated in Figure 5.

A brief discussion will show how conformal mapping is to be applied to the problem. Consider a series of contours C_n in the Z-plane. A particular orthogonal, given by a function $\xi(x, y)$, intersects each contour C_k at a point P_k and makes an angle α_k with the normal to C_k at that point. Assume that the contour C_{k+1} represents a depth less than that of C_k. Then the orthogonal is bent, as the waves are refracted, so that the angle α_{k+1} at P_{k+1} will be less than α_k. The change in angle is given by Snell's Law.

$$\sin \alpha_k / \sin \alpha_{k+1} = L_k / L_{k+1} \quad \text{(13)}$$

Suppose that a conformal transformation, w = f(z), is applied and that it transforms the contours C_n is the Z-plane into a set of contours S_n in the W-plane. Relations exist between the

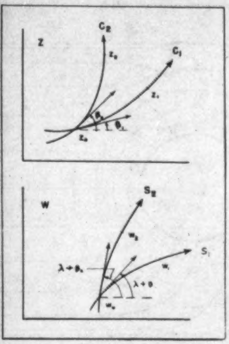

Fig. 4--Schematic representation of the transformation of two intersecting curves from the Z-plane to the W-plane by w = f(z); the angle between C_1 and C_2 at z_0 is equal to the angle between S_1 and S_2 at w_0

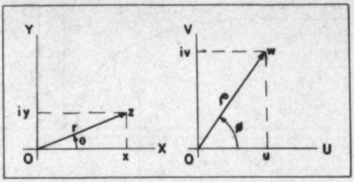

Fig. 5--The coordinates used in the Z- and W-planes; left, the Z-plane; right, the W-plane

coordinates x, y in the Z-plane and u, v in the W-plane. By substitution from these relations the function $\xi(x, y)$ is transformed into a function $\eta(u, v)$. The points P_n become a set of points Q_n where $\eta(u, v)$ intersects each of the contours S_n. Since angles are preserved in the transformation the angle between the curve, given by $\eta(u, v)$, and the normal to the contour S_k at the point of intersection Q_k is still α_k. Then the change of angle α_k at Q_k to α_{m+1} at Q_{k+1} is given by (13), exactly as in the Z-plane. Therefore the curve $\eta(u, v)$ in the W-plane obeys Snell's Law, that is, it represents an orthogonal. This argument indicates the validity of the application of Snell's Law to any complicated bottom contour configuration. The refraction of an orthogonal given by (10) obeys Snell's Law. Therefore the transform of (10) by w = f(z) is an equation for an orthogonal passing over a sloping bottom with contours given by the transform of the lines x = constant.

Usually we are concerned with the refraction of a bundle of orthogonals that are originally parallel in deep water, that is, parallel at their intersection with the contour $L/L_0 = 1$. A group of orthogonals parallel at the contour $L/L_0 = 1$ in the Z-plane makes a given angle with the contour. When the transformation to the W-plane is applied the transformed contour will, in general, be curved. Since the angles between the orthogonals and the contour remain the same, the orthogonals will no longer be parallel in the W-plane in deep water. It is, however, possible to find the equation for a set of orthogonals in the W-plane that are parallel at $L/L_0 = 1$ and which fulfill the assumption of a straight deep water wave crest. If α_0 in (10) is chosen to vary properly along the contour $L/L_0 = 1$ in the Z-plane, it is possible to map the orthogonals in the Z-plane into orthogonals that are parallel in deep water in the W-plane.

Circular island--The first transformation considered is given by

$$w = e^z \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (14)$$

Under this transformation the coordinates x, y in the Z-plane are related to ρ, ϕ in the W-plane by

$$\left.\begin{aligned} \rho &= e^x \\ \phi &= y \end{aligned}\right\} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (15)$$

Thus (14) transforms the straight lines $x = \gamma$ in the Z-plane into circles $\rho = e^\gamma$ in the W-plane. The coastline is the circle $\rho = 1$; the contour $L/L_0 = 1$ is the circle $\rho = e$. The slope of the bottom is obtained by substitution from (15) into (8) and is given by

$$\left.\begin{aligned} d &= (\log_e \rho/2\pi) \tanh^{-1} (\log_e \rho) & 1 \leq \rho < e \\ d &= \infty & e \leq \rho < \infty \end{aligned}\right\} \quad \dots\dots\dots\dots \quad (16)$$

The original straight refraction zone, then, has been transformed into a circular island. The bottom profile is shown in Figure 6. Note that the elevation of the island for $0 \leq \rho < 1$ is arbitrary; in the figure it is shown as zero.

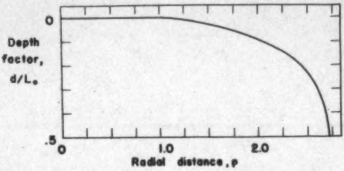

Fig. 6--The bottom profile for the circular island

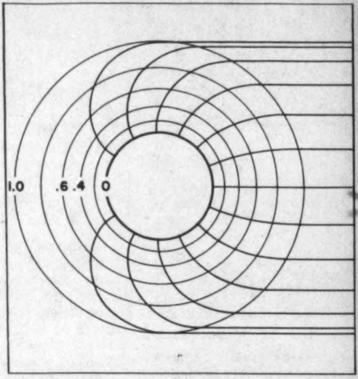

Fig. 7--Orthogonals to a wave train approaching the circular island from the right; the circular bottom contours are for intervals of L/L_o equal to 0.2; $L/L_o = 0$ is the shore; $L/L_o = 1$ indicates the beginning of refraction

Eq. (17), for the orthogonals approaching the circular island, is obtained from (10) by applying (15).

$$\log_e \rho = \sqrt{\csc^2 \alpha_o - (\phi - \phi_1)^2} \; \ldots\ldots \; (17)$$

Here ϕ_1 is determined by the angular coordinate Φ of the point of intersection of the orthogonal and the circle $\rho = e$. When the U-axis is oriented parallel to the deep water wave direction the angle $\alpha_o = \Phi$. The constant ϕ_1 is then given by

$$\phi_1 = \Phi - \cot \Phi \; \ldots\ldots\ldots \; (18)$$

After substitution from (18) the result for the equation of the orthogonals may be written

$$\log_e \rho = \sqrt{\csc^2 \Phi - (\phi - \Phi + \cot \Phi)^2} \; \ldots\ldots\ldots\ldots\ldots\ldots \; (19)$$

Figure 7 shows the orthogonals to waves approaching the circular island. All the orthogonals that intersect the contour $L/L_o = 1$ ($d = \infty$) reach the shore of the island. The waves outside this contour are not refracted. Thus there is a shadow behind the island; its width is equal to the diameter of the circular contour $L/L_o = 1$. Note also that there is a region along the lee shore of the island, with angular width approximately equal to 60°, to which no waves are refracted.

The angle α at a particular point in the refraction zone $1 < \rho < e$ is the angle between the tangent to the orthogonal and the radial vector to that point. The tangent of α is given by

$$\tan \alpha = \csc^2 \Phi - (\phi + \cot \Phi - \Phi)^2/(\Phi - \cot \Phi - \phi) \; \ldots\ldots\ldots\ldots\ldots\ldots \; (20)$$

An expression for K_d (2) may be derived for the waves approaching the circular island. It is assumed that the deep water wave direction is parallel to the U-axis. Consider two orthogonals a short distance apart approaching the island, as illustrated in Figure 8. The lengths of the wave crest between the orthogonals in deep water, at $\rho = P$, and at any contour are given by

$$\left.\begin{aligned} \Delta b_o &= P \cos \Phi \, \Delta\Phi \\ \Delta b &= \rho \cos \alpha \, [\phi(P, \Phi + \Delta\Phi) - \phi(P, \Phi)] \end{aligned}\right\} \; \ldots\ldots\ldots\ldots\ldots\ldots \; (21)$$

Here α is the angle given by (20). K_d is the ratio of these lengths

$$\Delta b_o/\Delta b = P \cos \Phi \, \Delta\Phi / \left\{\rho \cos \alpha \, [\phi(P, \Phi + \Delta\Phi) - \phi(P, \Phi)]\right\} \; \ldots\ldots\ldots\ldots\ldots \; (22)$$

To evaluate K_d at any point, the distance between the orthogonals is decreased continuously. As $\Delta\Phi \rightarrow 0$, (22) has the limit given by

$$K_d{}^2 = P \cos \Phi / [\rho \cos \alpha (d\phi/d\Phi)] \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (23)$$

After the differentiation is performed on (19), the result for $K_d{}^2$ is

$$K_d{}^2 = P \cos \Phi / [\cos \alpha (1 + \csc^2 \Phi - \cos \Phi / \sin^2 \Phi \sqrt{1 - \log_e{}^2 \rho \, \sin^2 \Phi})] \; \ldots\ldots\ldots\ldots\ldots \; (24)$$

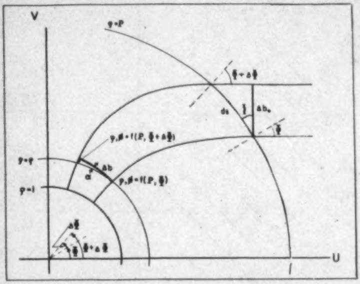

Fig. 8--Schematic representation of the quantities in the derivation of K_d for the circular island; two orthogonals are shown, their distance apart greatly enlarged

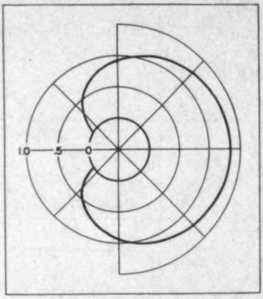

Fig. 9--The variation of K_d at the shore of the circular island for a wave train approaching from the right; values are read as on a polar diagram except that $K_d = 0$ is represented by the first circle instead of the center; the circle $K_d = 0$ also corresponds to the shore of the island; for example, the value of K_d at the point on the shore given by $\phi = 90°$ is 0.95

In particular, at the shore, the expression for $K_d{}^2$ has the form:

$$K_d{}^2 = [P \cos \Phi(1 + \cos \Phi)]/(2 + \cos \Phi) \; \ldots\ldots \; (25)$$

The variation of K_d at the shore of the circular island is shown in Figure 9 for a wave train approaching from the right. $K_d > 1$ along most of the forward shore; the waves are higher there than they would be due to the shoaling effect alone. From the point on the shore given by $\phi = 80°$, and along the lee shore, $K_d < 1$; the waves are lower. The maximum wave height is at the point on the shore given by $\phi = 0°$. Over a length of the lee shore given by an angular width of approximately 60° the wave height is zero (compare with Fig. 8).

Reef with parabolic contours--The transformation given by (26) changes the straight lines $x = a$ in the Z-plane into the parabolas (27) in the W-plane.

$$w = z^2 \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (26)$$

$$\rho = a^2 \sec^2 (\phi/2) \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (27)$$

The coastline in the W-plane is the negative U-axis. Thus the straight shore line with parallel bottom contours in the Z-plane has been transformed into a straight line reef with parabolic contours around it in the W-plane. The equation for the orthogonals may be obtained by first writing (10) in polar coordinates and then transforming the coordinates by (26). The result is the equation of a limaçon

$$4\rho m^2 \sin^2 (\phi/2) = (\rho + m^2 - \csc^2 \alpha_0)^2 \; \ldots\ldots\ldots\ldots \; (28)$$

Eq. (28) represents an orthogonal between the contour $L/L_0 = 1$ (the parabola $P = \sec^2(\Phi/2)$) and the shore (the negative U-axis). A general discussion of this transformation is given by BATEMAN [1944]. A more convenient form of the result is

$$\sqrt{\rho} = m \sin (\phi/2) \pm \sqrt{\csc^2 \alpha_0 - m^2 \cos^2 (\phi/2)} \; \ldots\ldots\ldots\ldots\ldots\ldots \; (29)$$

The constant m is given by

$$m = \sqrt{P} \sin (\Phi/2) \mp \sqrt{\csc^2 \alpha_0 - P \cos^2 (\Phi/2)} \; \ldots\ldots\ldots\ldots\ldots\ldots \; (30)$$

Here P and Φ are the polar coordinates of the point of intersection of the orthogonal and the parabola $P = \sec^2 (\Phi/2)$. The upper signs are used in (29) and (30) if the orthogonal intersects the first contour on the side of the normal to the contour nearer to the origin; the lower signs are

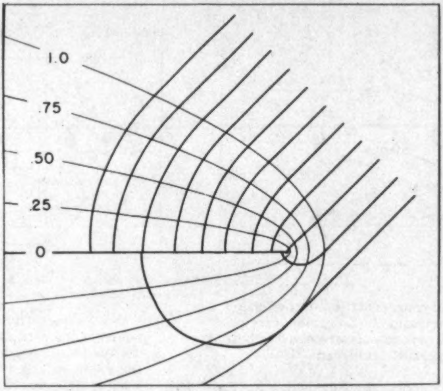

Fig. 10--Orthogonals to a wave train approaching the reef parallel to the line $\phi = 45°$ in deep water; contour lines are marked in values of L/L_0; the heavy line is the reef

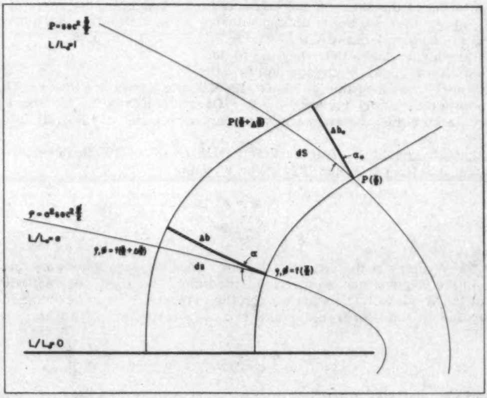
$P = \sec^2 \frac{\phi}{2}$
$L/L_0 = 1$
$P(\theta + \Delta\theta)$
Δb_o
dS
α_o
$P(\theta)$
$\rho = a^2 \sec^2 \frac{\phi}{2}$
$L/L_0 = a$
$\rho, \phi = f(\theta + \Delta\theta)$
Δb
α
ds
$\rho, \phi = f(\theta)$
$L/L_0 = 0$

Fig. 11--Schematic representation of the quantities in the derivation of K_d for the parabolic reef; the distance between the two orthogonals is greatly enlarged

used if the orthogonal is on the other side of the normal.

Figure 10 shows the refraction of a wave train approaching the reef from a deep water direction parallel to the line $\phi = 45°$. The convergence of the orthogonals near the tip of the reef indicates that the wave height is considerably greater there than in deep water. Along the lee shore there is very great divergence of the orthogonals; the waves there are much lower than in deep water.

An expression can now be derived for K_d by a method similar to that used for the circular island. Consider two orthogonals a short distance apart approaching the reef, as illustrated in Figure 11. Then it follows that

$$K_d^2 = dS \cos \alpha_0 / ds \cos \alpha$$

After the introduction of an expression for the differential length element this expression becomes

$$K_d^2 = [\cos \alpha_0 \sec^3 (\Phi/2)]/[\cos \alpha \sec^3 (\phi/2)(d\phi/d\Phi)] \quad \ldots\ldots\ldots\ldots \quad (31)$$

The expression for the derivative $d\phi/d\Phi$ is very complicated, but, for the special case when the orthogonals in deep water are parallel to the U-axis, it becomes simpler. For this case

$$\left.\begin{aligned} \alpha_0 = \Phi/2 \; ; \; \tan \alpha &= [\sqrt{\rho} \cos (\phi/2)]/[\sqrt{\rho} \sin (\phi/2) - m] \\ d\phi/d\Phi = [2a \tan (\phi/2)(dm/d\Phi) &- 2m(dm/d\Phi) - \csc^2(\Phi/2) \cot(\Phi/2)]/ \\ &[a \sec^2(\phi/2)(a \tan (\phi/2) - m)] \end{aligned}\right\} \ldots \quad (32)$$

Here m, $dm/d\Phi$ are given by

$$m = \tan (\Phi/2) - \cot (\Phi/2)$$

$$dm/d\Phi = 2 \csc^2 \Phi$$

The computations for K_d have been carried out for this case.

In Figure 12 the orthogonals for a wave train approaching the reef with a direction of travel parallel to the U-axis in deep water are shown. There is convergence of the orthogonals near the tip of the reef; elsewhere there is divergence. In Figure 13 the lines of constant K_d are drawn for this direction. $K_d = 1$ along the contour $L/L_0 = 1$, and outside it, since there the wave height is just equal to the deep water wave height. $K_d > 1$ only in a small region near the tip of the reef. It should be pointed out that, for the transformation (26), the origin in the W-plane is a singular point. This, in turn, introduces a singularity into the function for K_d such that $K_d = \infty$ at the origin (the tip of the reef) but is regular everywhere else. This result is not too damaging, however, since the waves actually break before they reach the shore. It is seen, by comparison of the two figures, that along certain orthogonals the wave height first decreases, and then increases, as the wave approaches the shore.

Bay with parabolic contours--The straight contours in the Z-plane for the function L/L_0 given by (11) may now be considered. The lines x = 1 and x = 2 are transformed by (26) into the parabolas

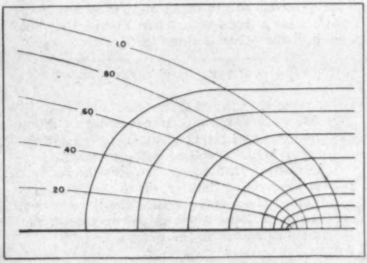

Fig. 12--Orthogonals to a wave train approaching the reef from a direction parallel to the U-axis in deep water; contours are drawn for different values of L/L_0; only the upper half of the pattern is shown; the figure is symmetrical about the dark line representing the reef

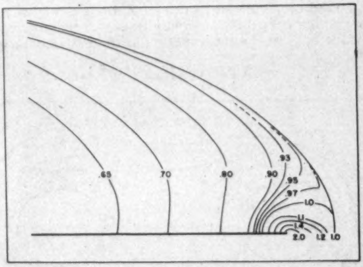

Fig. 13--Isopleths of K_d for a wave train approaching the reef from a direction parallel to the U-axis; only the upper half of the pattern is shown; the figure is symmetrical about the heavy line representing the reef

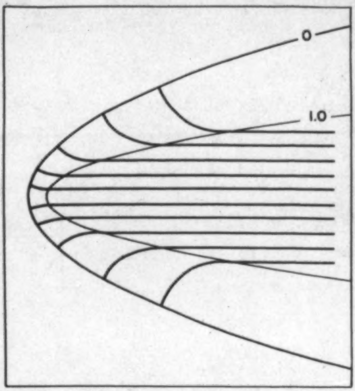

Fig. 14--Refraction of a wave train moving up the bay parallel to the U-axis; only two contours are shown; $L/L_0 = 1$ indicates the beginning of refraction; $L/L_0 = 0$ is the shore

$$\left.\begin{aligned}\rho &= \sec^2 (\phi/2)\\ \rho &= 4 \sec^2 (\phi/2)\end{aligned}\right\} \ldots\ldots (33)$$

Thus, after reference to (11), the first parabola represents the contour $L/L_0 = 1$; the second is the contour $L/L_0 = 0$. Therefore the original refraction zone has been transformed into a bay. Figure 14 shows the refraction of a wave train moving up the bay, parallel to the U-axis in deep water. Note that the refraction zone along the bay becomes wider toward the right and the angle α_0 increases in that direction. Therefore the refraction effect increases at greater distances from the head of the bay.

Twin islands--The next transformation is

$$w^2 = 1 + e^z \ldots\ldots\ldots (34)$$

The coordinates x, y in the Z-plane are related to ρ, ϕ in the W-plane by

$$e^{2x} = \rho^4 - 2\rho^2 \cos (2\phi) + 1 \ldots\ldots (35)$$

$$\tan y = [\rho^2 \sin(2\phi)]/[\rho^2 \cos(2\phi) - 1] \ldots\ldots (36)$$

From (35) it is seen that the contour lines $x = \gamma$ in the Z-plane are transformed into the curves $\rho^4 - 2\rho^2 \cos(2\phi) + 1 = e^{2\gamma}$ in the W-plane. This is the equation for a family of Cassini's ovals. If the straight beach in the original Z-plane is represented by the strip $-0.4 \leq x \leq 0.6$, the contour lines are given by $x = 0.6$ for $L/L_0 = 1$, $x = 0.4$ for $L/L_0 = 0.8$, $x = 0.2$ for $L/L_0 = 0.6$, $x = 0$ for $L/L_0 = 0.4$, $x = -0.2$ for $L/L_0 = 0.2$, and $x = -0.4$ for $L/L_0 = 0$. The transforms of these lines in the W-plane, that is, the curves given by (35) with $x = 0.6, 0.4, 0.2, 0, -0.2, -0.4$, are shown in Figure 15. The configuration, then, represents "twin islands" with oval depth contours around them.

By a procedure similar to the previous case, substitution from (35) and (36) into (10) leads to an equation for the orthogonals in which it is impractical to solve for ρ in terms of ϕ. Instead we may obtain an expression for $\cos 2\phi$ and $\sin 2\phi$ in terms of x and ρ from (35). Then a result can be derived for ρ in terms of x. This is (37), which actually links the coordinate ρ of the W-plane with the coordinate x of the Z-plane. Since, in the W-plane, each of the contour lines is characterized by a constant value of x, the easiest scheme for plotting points along an orthogonal is to first draw the L/L_0 contour lines corresponding to particular values of x, as in Figure 15. The value of ρ at the intersection of the orthogonal with each of the contour lines is then given by

$$\rho^4 = 1 + e^{2x} + 2e^x \cos\left\{\tan^{-1} [P^2 \sin 2\Phi/(P^2 \cos 2\Phi - 1)] \pm \sqrt{\csc^2 \alpha_0 - 0.36} \mp \sqrt{\csc^2 \alpha_0 - x^2}\right\} \quad (37)$$

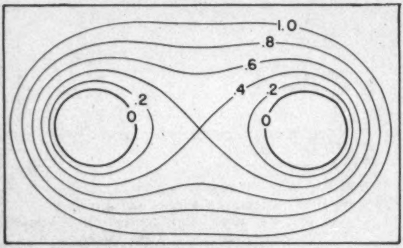

Fig. 15--Contour lines in values of L/L_0 for the twin island configuration; $L/L_0 = 0$ is the shore

In (37) P and Φ are the polar coordinates of the point of intersection of the orthogonal and the contour $L/L_0 = 1$. The upper signs are used if the orthogonal intersecting this contour makes the angle α_0 on the side of the normal to the contour farther from the origin. The lower signs are used if the angle is on the side of the normal nearer to the origin.

The orthogonals to a wave train approaching the twin islands are shown in Figures 16 and 17. Only the right half of the pattern is shown. In Figure 16 the deep water direction is parallel to the V-axis. For this direction it can be proved that all the orthogonals between those shown and the V-axis reach the

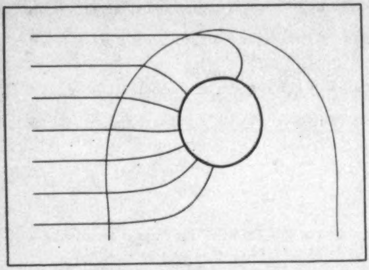

Fig. 16--Orthogonals to a wave train approaching the twin islands; the deep water direction is parallel to the V-axis; the pattern is symmetrical about the V-axis; only the right half is shown; the outer contour is $L/L_0 = 1$; the heavy oval is $L/L_0 = 0$, the shore

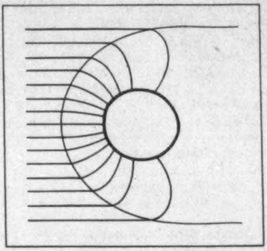

Fig. 17--Orthogonals to a wave train approaching the twin islands; the deep water direction is parallel to the U-axis; the contour lines are symmetrical about the V-axis; only the right half is shown, but no orthogonals are refracted to the island on the left; the outer contour is $L/L_0 = 1$; the heavy oval is $L/L_0 = 0$, the shore

shore of the island above the U-axis. No waves are refracted between the islands to the lee shore. In Figure 17 the orthogonals are drawn for waves advancing in a deep water direction parallel to the U-axis. Note that all the orthogonals reach the shore of the first island.

Results and conclusions--The methods employed in this paper are examples of a perfectly general technique. The actual cases that can be treated are restricted only by the mathematical complications that are introduced by any particular conformal transformation and, of course, by how well the transformed contour system simulates a natural beach structure. Thus the method offers a convenient means of developing various models to be used as a test of the theory. These tests should help to clarify the general validity of present ocean wave refraction theory since the assumptions made in this paper are usually made by most other investigators.

The theoretical results could be extended by a consideration, wherever possible, of diffraction effects. This is most important in the cases where a shadow occurs, as, for example, in the circular island.

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A NOTE ON THE TANGENTIAL TRANSFER OF ENERGY BETWEEN WIND AND WAVES

S. A. Schaaf and F. M. Sauer

Abstract--A mathematical treatment of the transfer of energy between wind and waves by tangential friction forces is given, consistent to the second degree of approximation. The results, when compared with the basic theory previously developed, show that the inclusion of second order terms results in a more consistent theory.

Introduction--The theoretical calculations of the relationships governing the growth and decay of waves formed by the action of the wind involves the determination of the energy transferred between the wind and the wave surface. This energy is transferred partially by normal pressure forces and partially by tangential shear stress caused by the relative velocity between the wind and water particle velocities. This calculation has been made by SVERDRUP and MUNK [1947]. However their calculation of the energy transferred by tangential stress seems inconsistent to the degree of approximation which they use. It is the purpose of this paper to develop the relationship governing the tangential transfer of energy consistent to the second degree of approximation using the wave steepness as a parameter.

The wave considered is one of finite amplitude, having the deep water velocity of progress, as given by Stokes [LAMB, 1945, p. 420].

$$C^2 = gL(1 + \pi^2 \delta^2 + \dots)/2\pi \quad \dots\dots (1)$$

The wave steepness, δ, is a small quantity, having a maximum value of 1/7 [LAMB, 1945, p. 418]. It is therefore appropriate to develop the tangential energy transfer by a perturbation in terms of δ, retaining only those terms of the order δ or less.

List of symbols

C = the velocity of progress of the wave
$\delta = H/L$, the wave steepness
H = the wave height
L = the wave length
x = the horizontal coordinate
y = the vertical coordinate
U = the wind velocity
u = the particle velocity at the wave surface in the x direction
v = the particle velocity of the wave surface in the y direction
τ_o = the shear stress at the wave surface
R_T = the average energy transferred by tangential shear stress per unit wave area
s = the length along the wave surface
θ = the slope of the wave surface
q_w = the particle velocity of the wave surface
q_a = air velocity adjacent to the wave surface
ρ = the air density
ϕ = designates a function

Analysis--The energy transferred per unit width per unit wave length is given by

$$R_T = (1/L)\int_o^L \tau_o\,(u \cos\theta + v \sin\theta)\,ds \quad \dots\dots (2)$$

where

$$u = \pi\delta C \sin(2\pi x/L) + \pi^2\delta^2 C \quad \text{[LAMB, 1945, p. 419]} \quad \dots\dots (3)$$

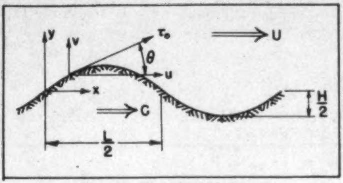

Fig. 1--The idealized wave

and

$$v = -\pi\delta C \cos(2\pi x/L) \;\ldots\ldots\; (4)$$

Impose on the system shown in Figure 1 a velocity equal to -C, causing the wave to remain stationary in space. Take the positive velocity to be to the left and upward. In the free stream far from the surface of the wave

$$q_a = C - U$$

On the wave surface assume that the air velocity has the form

$$q_a = (C - U)\,[1 + \pi\delta \cdot \phi(x/L)] \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots;\; (5)$$

where $\phi(x/L)$ is a periodic function. The particle velocity at the wave surface in the new system becomes

$$q_w = [(C - u)^2 + v^2]^{1/2} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (6)$$

Substituting (3) and (4) into (6), expanding in series and dropping terms of order δ^2 and higher as they appear, the particle velocity is, to the order δ,

$$q_w = \left\{C^2 - 2\pi\delta C^2[\sin(2\pi x/L) + \pi\delta]\right\}^{1/2} = C\left\{1 - \pi\delta[\sin(2\pi x/L) + \pi\delta/2]\right\} \ldots.\; (7)$$

Observations have indicated that the frictional forces present between the wind and wave surface is of a turbulent character. Assuming this to be so, the shear stress at the surface may be expressed in the form

$$\tau_o = (\rho C_D/2)\,(q_w - q_a)^2 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (8)$$

where the wind direction is as shown in Figure 1. The value of the drag coefficient, C_D, is taken as constant for all conditions of relative velocity and wave steepness. Substitution of the expressions for the air and particle velocities, expanding, and again dropping higher order terms in δ yields

$$\begin{aligned}\tau_o &= \rho C_D/2\left\{U + \delta[\pi(U - C)\phi - \pi C(\sin \overline{2\pi x/L} + \pi\delta/2))]\right\}^2\\ &= \rho C_D/2\left\{U^2 + 2U\delta[\pi(U - C)\,\phi - \pi C(\sin \overline{2\pi x/L} + \pi\delta/2))]\right\} \;\ldots\ldots\ldots\; (9)\end{aligned}$$

To the order δ

$$\cos\theta \doteq 1\,, \qquad \sin\theta \doteq \pi\delta\cos(2\pi x/L)\,, \qquad ds \doteq dx$$

Substitution of the above terms into (2), expanding and integrating yields to the order δ

$$R_T = \rho C_D \pi^2\delta^2\, CU[(U/2) - C + 2\eta(U - C)]/2 \;\ldots\ldots\ldots\ldots\ldots\; (10)$$

where η is defined by the expression

$$\eta = 1/L\int_0^L \phi \sin(2\pi x/L)dx$$

An upper limit for the value of η may be found from potential flow theory. The flow velocity near a wavy surface is given (in the velocity coordinate systems used here) by the equation [LIEPMANN and PUCKETT, 1947]

$$q_a = (C - U)\,[1 + \pi\delta\sin(2\pi x/L)]$$

Comparing this expression with (5), ϕ equals $\sin(2\pi x/L)$ and $\eta = 1/2$. For flows other than potential, the value of η will be less than this owing to boundary layer and separation effects over the wave profile. The actual magnitude must be determined by experiment or estimated from existing data.

Discussion--The expression developed for the average tangential transfer of energy may now be compared with Eq. (37) of SVERDRUP and MUNK [1947], which is repeated here

$$R_T = \gamma^2 \rho' \pi^2 \delta^2 C\, U^2$$

where $\gamma^2 \rho'$ corresponds to $\rho C_D/2$ used in this paper. Eq. (10) is best written for this comparison in the form immediately preceding simplification

$$R_T = \rho C_D \pi^2 \delta^2\, C\, U\, [U - U/2 + 2\eta(U - C) - C]/2 \quad \text{(10a)}$$

An investigation of the origin of the terms in (10a) yields the following information. The first term represents the contribution of the transport velocity times the average horizontal shear. The second term is the contribution of the vertical velocity times the average vertical component of shear. The third term represents the variation in shear due to the variation of wind velocity near the wave surface, and the fourth term is the variation in shear due to the variation of the water particle velocity at the wave surface. All of the above terms are the result of second order variations and are of equal order of magnitude; hence all should be included in any analysis. The analysis of SVERDRUP and MUNK [1947] leading to their Eq. (37) considers only the average shear and the transport velocity; hence their result contains only the first of the terms in (10a). In view of this disparity, it is recommended that the entire analysis of SVERDRUP and MUNK be reinvestigated.

Equation (10) yields positive values of R_T only for $C < U$. Thus this analysis limits the growth of waves to the region where the wave velocity is less than the wind velocity. Eq. (37) of Sverdrup and Munk does not limit the wave velocity for positive transfer, and their data show waves generated at wave velocities exceeding the wind velocity. However, the data recently gathered by JOHNSON [1950] show that the majority of waves generated are in the region of $C \leq U$, only a comparatively small number having $C > U$. Waves in the latter region may have been generated under conditions not covered in the present analysis.

Two such conditions suggest themselves. Waves may be generated in a region of substantial velocity gradient; hence measured wind velocities may be lower than the velocity of the undisturbed flow. This would create the impression that the waves are moving faster in relation to the wind than they actually are. Secondly, short period waves in the generating area may disappear, transferring their energy to other waves. Such waves might occasionally exceed the wind velocity.

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MEASUREMENT OF INTERCEPT DISTANCES IN THIN SECTION

Felix Chayes

Abstract--Use of a low-pitched thread on the main screw of the mechanical stage of the point counter and substitution of an electric, ten-key adding machine for the cumulative counter used in modal analysis permits rapid measurement of grain intercept distances in thin section. Distribution of individual measurements is badly skewed and sometimes J-shaped, with a preponderance of short runs and a scarcity of long ones, but random sampling experiments show that even in extreme cases means of samples of ten are essentially normal. The measuring technique and some results are described.

In descriptive petrography the study of grain size is beset by difficulties both theoretical and practical. It is possible that our understanding and interpretation of grain-size differences would now be much further advanced if we had a practical measuring technique that would permit the accumulation of sufficient, and sufficiently reliable, data in reasonable time. The point counter designed for modal analysis [CHAYES, 1949] is easily adapted for this type of measurement. It is only necessary to substitute a thread of low pitch in the traversing mechanism and replace the (cumulative) counting block with a ten-key adding machine.

By the use of a suitably fine thread on the main screw of the mechanical stage the distance between clicks may be made small enough for any practical purpose. A 0.05 mm translation between clicks is suitable for work on rocks as fine as the Westerly and Pownal granites. Of course, a new thread nut must be cut for the screw. Changing the screw requires only a few minutes, so that it is not necessary to have separate mechanical stages for analytical work and grain-size measurement, though this would no doubt be desirable in a large laboratory.

An electrically operated ten-key adding machine is essential for rapid work. The keyboard is easily memorized so that there is no need to take one's eye from the microscope during the operation. This type of machine is also particularly desirable because the printing bar is within easy reach and errors are seldom introduced by faulty return to the operating position after printing.

The measuring procedure is very simple. A number is assigned to each mineral; whenever a particular mineral lies under the X-hair intersection after a click its number is entered on the keyboard and printed on the tape. Tabulation and calculation are greatly facilitated if a blank space is left after each five numbers printed. After a little practice, the operation of the machine, including the spacing, becomes virtually automatic. Anyone with experience at touch typing will soon find that he is able to work as fast as the machine will print. This is somewhere between 50 and 75 single digit numbers per minute on the three instruments I have tried. Of course, such speed can be maintained only if the measurements are made along an arbitrary direction; when this is the case, as it happens to be in my work, the traverse of an inch requires about ten minutes and yields six feet or so of paper, containing some 450 entries.

A frequency table is drawn up from the tape in another five or ten minutes. (It will take much longer and contain many more errors unless blank spaces are systematically distributed through the tape, as described above.) Entries in the table are the frequencies of occurrence of runs of length 1, 2, 3, ... n clicks for each mineral. From these the average run-lengths are computed. Multiplication of the average run-length $\bar{n}$ by the distance between clicks d gives the average intercept length in mm in the direction of traverse. (If each boundary of a given grain coincides exactly with a click point, the measured distance is $(n - 1)d$. There is almost always some overlap at either or both ends, however, so that $(n - 1)d$ under-estimates the actual distance by an amount, e, such that $0 \leqslant e \leqslant 2n$. Assuming a uniform distribution of e in this range, $\bar{n}d$ is a better estimate of the average intercept distance than $(\bar{n} - 1)d$ or $(\bar{n} + 1)d$.)

As might be expected, the assemblage of measurements for any mineral is usually strongly skewed. When $\bar{n}$ is sufficiently small the sample distribution is J-shaped, with a great preponderance of very short runs and a scarcity of long ones. Single values drawn from such a parent population are scarcely of much use. It is a commonplace, however, that means often tend to be

Table 1--Triangular parent population similar to observed distribution of grain intercepts

Run-length (number of clicks)	Relative frequency as per cent of whole
1	18.09
2	15.84
3	13.60
4	11.36
5	9.12
6	6.87
7	4.63
8	2.39
9	2.26
10	2.11
11	1.96
12	1.81
13	1.66
14	1.51
15	1.36
16	1.20
17	1.06
18	0.90
19	0.75
20	0.60
21	0.45
22	0.30
23	0.15

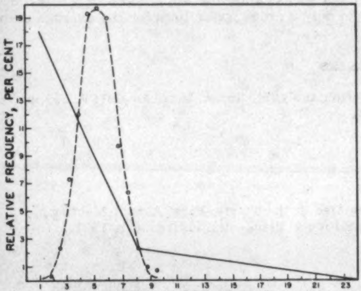

Fig. 1--Frequency distribution for run lengths in parent population similar to observed distribution (solid lines), and for means of samples of ten drawn from this population (small circles); broken line represents the normal equation fitted to the means; data from Tables 1 and 2

Table 2--Distribution of means of samples of ten drawn from the population shown in Table 1

Means (class width 0.6 clicks)	Observed frequency	Calculated frequency
1.5-2.1	1	1.6
2.2-2.8	7	7.7
2.9-3.5	22	18.5
3.6-4.2	36	36.3
4.3-4.9	58	56.0
5.0-5.6	59	58.8
5.7-6.3	57	56.0
6.4-7.0	29	36.3
7.1-7.7	19	18.5
7.8-8.4	7	7.7
8.5-9.1	3	1.6
9.2-9.8	2	0.5

normally distributed even though drawn from non-normal universes. This proposition can be demonstrated for a great variety of distributions, including the exponential and triangular, but the demonstration is meaningful only to the mathematically elite. I was therefore obliged to examine the matter the hard way. The results are shown in Tables 1 and 2.

In column 2 of Table 1 are listed relative frequencies of runs of the lengths (number of clicks) shown to the left, in a triangular parent population defined by the area under the two lines $y = 16.86 - 1.86x$; $1 \leqslant x \leqslant 8$; $y = 3 - 0.125x$; $8 < x \leqslant 23$, where y is frequency and x is run-length. These two lines yield an easily sampled population similar to the sample distribution obtained by combining results for the first nine traverses run on thin sections of Westerly granite.

Using Tippet's table of random numbers, I drew 300 samples of ten from this parent population. The resulting means are shown in the first and their frequencies in the second column of Table 2. The third column of Table 2 shows class frequencies calculated from a normal curve fitted to the data. In Figure 1 the two straight lines describe Table 1, the data points are as shown in column 2 of Table 2, and the dashed line represents the normal curve from which entries in column 3 of Table 2 were computed.

It is evident that means based on as many as ten measurements will be, for all practical purposes, normally distributed. On a rock as fine grained as Westerly granite a traverse of 25 mm will usually contain 30 or more runs each of quartz, potash feldspar, and plagioclase. Even on one as coarse as Barre the figure will rarely drop much below 15.

Even in simple comparisons it is useful to be able to regard the average intercept as a normal variate, and for more complex experimental designs it is practically indispensable. In the model used above, for instance, individual measurements range all the way from one to 24 clicks, corresponding to intercept lengths of 0.5 to 1.25 mm. The population mean is 5.3 clicks, or 0.26 mm, Table 3--Average intercept length, $\bar{n}d$, in mm, for one-inch traverses of a slide of Westerly granite

Traverse number	Quartz	Potash feldspar	Plagioclase
1	0.25	0.23	0.23
2	0.28	0.20	0.25
3	0.22	0.21	0.21
4	0.28	0.25	0.20

but a single measurement may miss this value very widely. Now the standard deviation for means of samples of ten is 1.33 clicks; and as the distribution of means is essentially normal for samples of this size, we may infer at once that their dispersion will remain normal and decrease with increasing sample size in the usual fashion. A sample of 30 runs, for instance, may be regarded as three samples of ten runs, and its standard deviation ought to be about $1/(2n)^{1/2}$ or $6^{-1/2}$ that of the smaller sample. In the example given above this would come to 0.54 clicks, which is certainly good enough for ordinary purposes, even when the mean is as small as 5.1.

Table 3 shows results for four traverses of a thin section of Westerly granite. The traverses were parallel and spaced at five-mm intervals. Individual measurements in each case yielded J-shaped histograms; they were in fact part of the data which suggested the sampling experiment described above. Yet the range of average values for any mineral does not exceed 0.06 mm, barely more than the least count of the instrument. Each line in the table represents about 30 min work, and each entry is an average based on about 30 measurements.

The procedure described permits rapid accumulation of reliable data, though of course it must not be regarded as universally applicable. Clearly the variance of an average intercept value will be a function both of the "true average intercept" and of the number of measurements on which the experimental value is based. Experimental designs presupposing homogeneous variance should not be applied unless grain-size differences are known to be reasonably small, and for best results averages to be used in multiple comparisons should be based on about the same number of measurements. Finally, too short a translation distance between clicks will involve tremendous waste of time and paper in studies of coarse-grained rocks, while the use of too long a translation distance on fine-grained material is bound to yield only a crude upper limit for the average intercept.

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ECLOGITIC AND GLAUCOPHANE AMPHIBOLITES IN VENEZUELA

Gabriel Dengo

Abstract--Several occurrences of amphibolites with sodic pyroxenes and amphiboles are found in association with garnet amphibolites within the metamorphosed sedimentary rocks of northern Venezuela. They are interpreted as having been, originally, shallow basic intrusive rocks and perhaps tuffaceous sediments. Some of these rocks have affinities with eclogites, and are interpreted as a type of metastable mineral assemblage formed under the physical conditions of medium grade dynamothermal regional metamorphism. The rocks in question do not belong to as high temperature and high pressure facies as is held for other eclogites. The glaucophane schists seem to have had a similar origin though perhaps formed under lower grade conditions of metamorphism. The conditions that are conducive to the formation of these metastable assemblages are not known. There is a possibility that they may be due to a particular bulk composition, to the action of permeating solutions during metamorphism, or to the catalytic action of shearing stress.

Introduction--During the course of a regional geological investigation in the Cordillera de la Costa of Venezuela, undertaken jointly by the Instituto Nacional de Minería y Geología of that country and Princeton University, the author had the opportunity of studying briefly some amphibolites and glaucophane schists. Although these rocks should be studied in more detail, it seems pertinent to present at this time some views on the problems involved in the interpretation of their origin.

Mention of the occurrence of amphibolites in northern Venezuela has been made since the times of the work of HUMBOLDT [1799-1804], and later by WALL [1860] who called them eclogites, and by LAMARE [1927]. More recently RUTTEN [1940] mentioned an amphibolite-eclogite from the island of Margarita, and HESS and MAXWELL [1949] described some amphibolites from the same island. Several new localities have been found lately (see Fig. 1), and it is possible that others exist, because a large part of the Cordillera has not been covered even by a geological reconnaissance. A

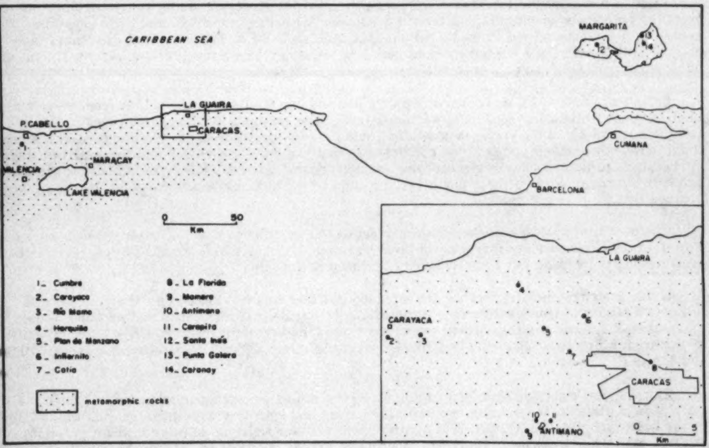
CARIBBEAN SEA
MARGARITA
12
13
14
LA GUAIRA
P. CABELLO
CARACAS
1
MARACAY
VALENCIA
LAKE VALENCIA
CUMANA
BARCELONA
0
50
Km
1_ Cumbre
2_ Carayaca
3_ Río Mamo
4_ Horquilla
5_ Plan de Manzano
6_ Infiernito
7_ Catia
8_ La Florida
9_ Mamera
10_ Antimano
11_ Carapita
12_ Santa Inés
13_ Punta Galera
14_ Coronay
metamorphic rocks
LA GUAIRA
CARAYACA
2
3
4
5
6
7
8
CARACAS
10
11
9
ANTIMANO
0
5
Km

Fig. 1--Index map showing location of amphibolites in northern Venezuela

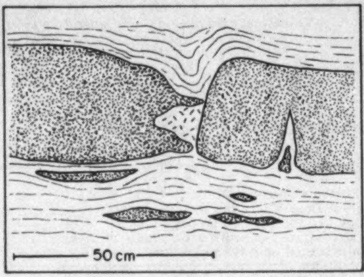

Fig. 2--Boudinage structure in amphibolite

description of the amphibolites and related rocks in the vicinity of Caracas has been already presented [DENGO, 1949]. The purpose of this paper is to state the problems involved in the origin of the rocks in question, presenting the descriptive material only in a summarized form.

Geologic setting--Amphibolites of variable mineralogical composition are found within migmatitic gneisses, quartz-muscovite schists, crystalline limestones, and calcareous mica schists, all of which belong to the so-called Caracas group. They are more frequently found within the mica schists. Commonly they form small bodies of lenticular shape, some of which are due to boudinage of larger masses (see Fig. 2). Others occur as larger sheet-like bodies whose contacts are conformable with the foliation of the enclosing schists. Several of the larger bodies are found near crystalline limestones, and some small lenses occur within the limestones. The fact that other bodies occur within gneisses and mica schists indicates that the association with the limestones does not imply any special genetic conditions for the formation of the amphibolites. Similar occurrences of amphibolites and eclogites near limestones have been found elsewhere [ESKOLA, 1921; FIEDLER, 1936; and ALDERMAN, 1936].

Petrographically two types of rocks are most abundant, garnet amphibolites and epidote-garnet amphibolites, in which the amphibole is a hornblende. In association with them, but in small amounts, occur rocks of different mineralogical composition, among them glaucophane rocks, some consisting largely of glaucophane and garnet, and others whose essential minerals are epidote and glaucophane. There are intermediate types of amphibolites which have both glaucophane and hornblende in variable proportions. Still rarer are rocks which carry the green clinopyroxene omphacite. These rocks are designated here as eclogitic amphibolites because none of them contains sufficient pyroxene to warrant the name of eclogite. No true eclogites, that is, rocks which consist mainly of omphacite and pyrope-almandite garnet, have been found in the region thus far. Details of the mineralogical composition of these rocks are given in Table 1. The main optical properties of the essential minerals are presented in Table 2.

Some of the amphibolites show a well developed planar structure which results from the alternation of garnet and amphibole, and from the subparallel arrangement of amphibole crystals. This structure is best developed in the larger masses such as those at Infiernito and Rio Mamo (see Fig. 1). Other rocks are massive and do not show foliation. The garnetiferous varieties generally show porphyroblastic garnets with well developed crystal faces.

Samples from two small bodies of amphibolite and one of glaucophane schist from the vicinity of the town of Antimano (see Fig. 1) were analyzed. The chemical analyses are given in Table 3, and the mineralogy of the rocks is shown in Table 1. A comparison of the chemical analyses and the mineralogical composition of the rocks shows that the decrease of FeO and increase of Fe_2O_3 corresponds to an increase of glaucophane and a decrease of hornblende. The amount of glaucophane in the rocks does not bear any direct relation to the total amount of Na_2O in the chemical composition.

The chemical analyses of the rocks in question are similar to those of basic igneous rocks. The field relations indicate that most of them were emplaced as sills, although a few seem to have been originally bedded, and possibly were tuffaceous sediments.

If this interpretation is correct, the amphibolites and related rocks in northern Venezuela indicate a period of igneous activity characterized by hypabyssal intrusions and probably local extrusions of a basic magma. These rocks were emplaced prior to the regional metamorphism of the area, which most probably took place during the latter part of the Cretaceous period [HESS and MAXWELL, 1949].

Eclogite and glaucophane schist problems--True eclogites, eclogitic amphibolites, and certain types of glaucophane schists (particularly garnet and epidote glaucophane schists which belong to the basic type [WASHINGTON, 1901]), have chemical compositions similar to basic igneous rocks, but are much denser. Therefore, a problem arises in trying to explain the conditions under

Table 1--Mineralogical composition of some Venezuelan amphibolites and related rocks (estimated percentages)

Locality[a]		Rock	Mineral															
			Garnet	Hornblende	Glaucophane	Zoisite	Clinozoisite	Epidote	Omphacite	Albite	Muscovite	Chlorite	Quartz	Sphene	Rutile	Apatite	Pyrite	Megnetite-Ilmenite
Infiernito	6	Eclogitic amphibolite	30	50	b	b	..	..	b	..	b	..	b	..	b	b	b	..
Plan de Manzano	5	Eclogitic amphibolite	25	50	..	b	..	..	15	..	b	..	b	..	b	..	b	..
Horquilla	4	Garnet-galucophane rock	30	b	60	..	..	b	..	..	..	b	..	..	b	..	..	b
Carapita (top)	11A	Garnet amphibolite	20	50	b	b	20	b	..	b	..	..	b	..	b	..	..	b
Carapita (bottom)	11B	Epidote amphibolite	..	60	..	..	b	25	..	b	..	b	b	..	..	..	..	b
Carapita	11C	Epidote-glaucophane schist	..	60	..	..	..	30	..	..	b	b	..	..	b	b	..	b
Antimano (top)	10A	Garnet-glaucophane amphibolite	25	30	30	..	b	10	..	..	..	b	..	b	..	..	..	b
Antimano (center)	10B	Epidote amphibolite	..	65	b	..	..	25	..	b	..	b	..	b	..	..	..	b
Antimano (bottom)	10C	Epidote-glaucophane amphibolite	..	b	65	..	..	25	..	..	..	b	..	b	..	..	..	b

[a] Number indicates locality in the index map (Fig. 1).
[b] Variable amount but less than ten per cent.

Table 2--Optical properties of minerals from selected amphibolites

Locality[a]		Mineral	Optic sign	2V	nβ	Dispersion optic axis	Extinction angle	Pleochroism
				°			°	
Infiernito	6	Garnet[b]	..	.....	1.782	..	.....	......
Plan de Manzano	5	Omphacite	+	Approx. 67	1.635	r>v	Approx. 41	......
Carapita	11	Hornblende	-	Approx. 80	1.657	r>v	Approx. 12	Z bluish green Y light green X nearly colorless
Antimano	10	Glaucophane	-	Approx. 50	1.635	r>v	Approx. 6	Z blue lavender Y light blue X nearly colorless
Horquilla	4	Glaucophane	-	.....	1.637	..	Approx. 8	Z dark blue Y light blue X nearly colorless
Plan de Manazano	5	Zoisite	+	Approx. 25	1.698	r<v	.....	......

[a] Number indicates locality in the index map (Fig. 1).
[b] Specific gravity = 3.92.

Table 3--Chemical analyses of Venezuelan amphibolites
(E. Chadbourn, analyst)

Item	11A[a]	11B[a]	11C[a]	10B[a]	10C[a]
SiO_2	50.51	47.64	46.44	49.41	49.69
Al_2O_3	13.48	15.43	14.92	15.12	14.78
Fe_2O_3	1.80	2.30	6.92	4.61	5.14
FeO	10.43	7.11	3.87	4.29	4.23
MgO	7.39	9.18	7.36	9.30	9.36
CaO	8.86	11.89	8.88	10.83	9.50
Na_2O	3.29	1.46	3.87	2.86	2.67
K_2O	0.21	0.20	0.36	0.11	0.81
H_2O+	2.02	3.32	2.24	2.38	2.65
H_2O-	0.05	0.24	0.14	0.15	0.24
TiO_2	1.34	1.03	1.19	0.71	0.77
P_2O_5	0.11	0.09	0.10	0.07	0.07
MnO	0.19	0.15	0.14	0.13	0.14
Total	99.68	100.04	99.87	99.97	100.05
Specific gravity at 22° C	3.168	3.048	3.194	3.138	3.118

[a] Number indicates locality in index map (Fig. 1).

11A	Garnet amphibolite (top) Carapita
11B	Epidote amphibolite (bottom) Carapita
11C	Epidote glaucophane schist Carapita
10B	Epidote amphibolite (center) Antimano
10C	Epidote-glaucophane amphibolite (bottom) Antimano

which these high density facies may be formed. The theory most widely accepted for the origin of eclogites is that they were formed by metamorphism of igneous rocks under conditions of very high pressure and temperature [ESKOLA, 1921; ALDERMAN, 1936; and FAIRBAIRN, 1943]. The garnet amphibolites associated with eclogites are explained by retrogressive changes or amphibolitization of pyroxenes in a larger body of eclogite.

There are regions where eclogites (eclogitic amphibolites) have been found in association with mica schists of medium metamorphic grade. BRIERE [1920] has described several cases from western France where eclogites occur associated with mica schists of the "meso-zone." WIESENEDER [1934] has described a similar case from the Eastern Alps. Most of the rocks which these authors have described and which occur under those conditions are eclogitic amphibolites. They carry almandite-rich garnet, omphacite, hornblende, glaucophane, zoisite, and clinozoisite. The Venezuelan eclogitic amphibolites are remarkably similar to these of French and Alpine occurrence both in mineralogy and in the degree of metamorphism shown by the associated schists. In Venezuela these rocks seem to have been formed under conditions of strong shearing stress. The associated schists show a pronounced development of b-axis lineation. The eclogitic amphibolites show a good planar structure but no megascopic lineation. It is reasonable to assume that the eclogitic amphibolites were formed under directed pressure at intermediate temperatures, and not at a great depth. That is, they were probably formed under the conditions which normally produce the amphibolite facies and not under those supposed to characterize the formation of the eclogite facies.

It is postulated here that the mineral assemblages of the eclogitic amphibolites may be a metastable association formed as a step in the change of basic igneous rocks to true amphibolites. A metastable mineral assemblage is one that is less stable than other assemblages of equal bulk composition. It is a well known fact that metastable assemblages may appear first during metamorphic reconstitution of a rock, according to the principle known as Ostwald's law. RIDDLE and FOSTER [1949] have postulated that kyanite, which is a high density mineral and which often occurs in eclogites, may be a metastable form. The eclogitic amphibolites must have been formed under conditions which favored the reaction of the anorthite molecule of the original plagioclase with olivine to form garnet. The soda of the albite molecule entered either a pyroxene or an amphibole. When retrogressive changes take place and the stable phase is attained, the sodic amphiboles and pyroxenes change into hornblende, and the soda goes again into the plagioclase which is reconstituted. In some of the amphibolites studied, poikiloblastic albite is present in those rocks in which hornblende is more abundant. Such rocks must have undergone some retrogression. The basic glaucophane schists present a similar case but probably represent a lower grade of metamorphism, according to TURNER [1948], in the greenschist to epidote-albite amphibolite facies. The similarity between the two groups of rocks has been pointed out by WASHINGTON [1901], FAIRBAIRN [1943], LACROIX [1941], and TURNER [1948].

Eclogites and glaucophane schists are similar not only in chemical composition, but also because they are rocks of high density, carry sodic minerals other than plagioclase without having excess Na_2O in their bulk composition, and have a similar mode of occurrence. There have been several localities reported where basic glaucophane schists and eclogitic amphibolites are associated, as in Greece [WASHINGTON, 1901], and Madagascar [BRIERE, 1920]. Transitional rocks have also been reported. One of the occurrences found in Venezuela (that is, Infiernito) is also a transitional rock.

Causes for the formation of metastable facies--Although the causes which may induce the formation of high density facies under conditions of medium grade metamorphism are not known, some views towards a possible explanation have been already advanced. WIESENEDER [1934] has suggested that the limiting factor in the formation of eclogites is not depth but a certain bulk composition. ALDERMAN [1936] thinks that the amount of albite molecule and the original composition of the pyroxene determine the formation and composition of omphacite during metamorphism.

If the eclogite mineral assemblages are really metastable, as it has been suggested here, it may not be inappropriate to establish a comparison between this case and experimental evidence bearing on the origin of anthophyllite. BOWEN and TUTTLE [1949] found that anthophyllite forms as a metastable phase, and that its formation is conditioned to certain total composition in the system $MgO-SiO_2-H_2O$. It is within reason to think that the controlling factor for the formation of other metastable phases is the total original composition of the rock.

Another possibility to consider is that the formation of sodic pyroxenes and amphiboles was the result of solutions present at the time of deformation. TALIAFERRO [1943] and SWITZER [1945] have shown that certain types of glaucophane schists and eclogites may be formed by hydrothermal action at low pressures. LACROIX [1941] has emphasized the role of solutions in the formation of glaucophane schists in New Caledonia. It is possible that under conditions of regional metamorphism the presence of solutions, without implying the addition of any substance, may be conducive to the formation of the rocks in question. FIEDLER [1936] has already suggested the influence of magmatic solutions in the formation of some eclogites in the Erzgebirge.

A third factor which must be taken into consideration in explaining the formation of high density facies is the action of shearing stress. It was stated above that some eclogitic amphibolites occur in association with rocks which show the effects of shearing stress. BACKLUND [1936] has considered that eclogitic amphibolites in Greenland were not formed under hydrostatic pressure but under conditions of extreme dynamic pressure acting on geosynclinal basalts and their tuffs. He thought that high temperature, under the same dynamic conditions, may cause the formation of true eclogites.

Summary--In this paper no final conclusion is reached in considering the origin of eclogitic amphibolites and glaucophane schists. However, the Venezuelan example is used to emphasize that there are cases where the field facts conflict with the current views about the origin of these rocks. One fact seems to be clear, that there are high density rocks which formed under conditions of regional dynamothermal metamorphism of intermediate grade, and not necessarily under uniform pressure or under high grade metamorphism.

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THE USE OF A TEMPERATURE-RUNOFF RELATIONSHIP IN WATER-SUPPLY FORECASTING

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Abstract--This paper describes briefly a relationship of temperature to seasonal snowmelt runoff. It is in the form of a progress report so as to bring to the attention of the reader the possibilities of evaluating the amount of water in the marginal fringe of the snow blanket that lies upon a watershed.

Water-supply forecasting as practiced by California Cooperative Snow Surveys, still demands continued research. As each year passes, the data for evaluating the many factors involved in such forecasts becomes more complete so that reappraisals of former assumptions are possible.

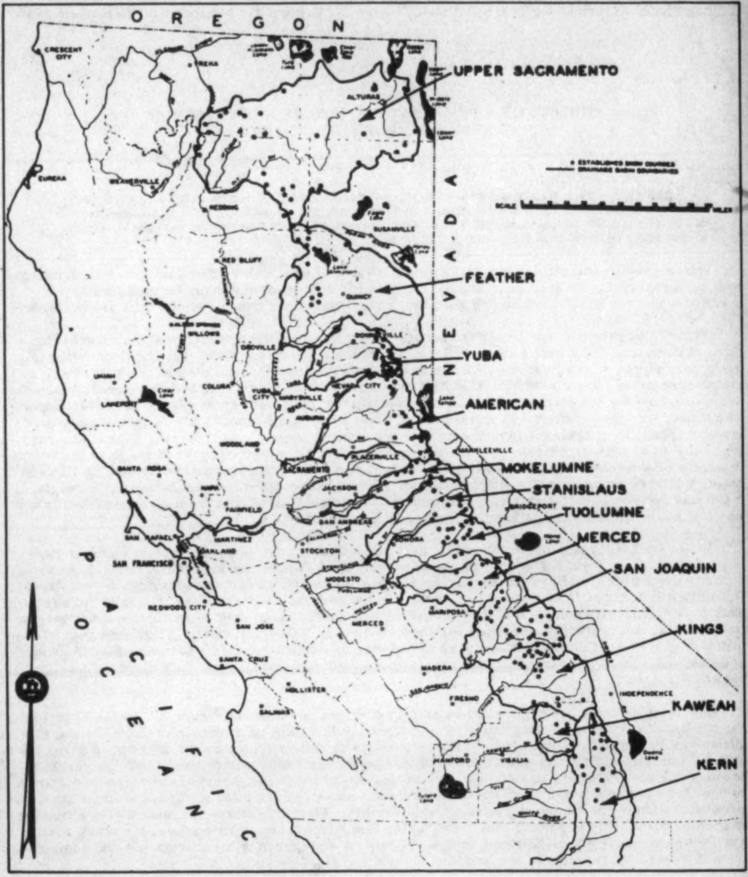
Figure 1 shows the location of the 12 major watersheds where streamflows are forecast by this organization. This wide latitude of location presents conditions which change from basin to basin as one progresses from the lava fields in the north, down through the granite watersheds of the central Sierra, to the high elevation arid-type areas of the south. Methods of forecasts are the same in all areas; however, emphasis of one contributing factor of runoff may be far more important in one area than another. Residual stream flow, a very important factor in the lava areas of the north, has small importance on the granite watersheds of the central Sierra. Again, soil priming, found to be very significant on the Kaweah Watershed (as reported by Fred Paget to the Western Snow Conference on February 27, 1945 in his paper "A new forecasting curve for the Kaweah") appears to have no appreciable effect on the watersheds where granite predominates. All of the many factors pertinent to water supply forecasting have varying effects from one watershed to the next. It has truly been said, "Each watershed is a law unto itself."

Water-supply forecasting practiced by California Cooperative Snow Surveys is dependent not only upon snow surveys, but is also highly dependent upon many other sources of data. However, at the present time forecasts are limited to what were considered predominantly snow-fed streams. Possibly it is for that reason alone that we have snow surveys so prominently displayed in our title. This paper deals with a method of forecast which is entirely based upon climatological and streamflow data. It was originally developed for the Kern River. The relationship is quite simple. On an ordinary graph sheet, mean temperatures are plotted as ordinates; observed runoff plotted as abscissas; and a family of curves drawn in accordance with historical April-July stream flows, as shown on Figure 2.

The possible accuracy of forecast using this diagram is shown on Figure 3. As the Kern River has not been forecast more accurately by any other method, this relationship is more than an idle curiosity. Explanation of why this relationship exists is quite simple, and is not new. A given temperature working on a smooth snow blanket should produce snowmelt in proportion to the varying areas of the snow blanket exposed. Combining this thought with the theory that in high mountain basins there is a relationship in late season between snowpack area and snowpack volume produces our explanation of the temperature-runoff relationship. Field conditions are such that verification of such a relationship is not too easy. Evaluating temperature, snowpack areas, snowpack volume, and snowpack runoff are all difficult, and would require exasperating measurements and computations if it were not possible to use an index method for all of these.

The index chosen for the temperature working on the area of snowpack is the April mean temperature for Springville, a station located just outside the watershed at the highest altitude in the vicinity and closest to the location of the snow fields in the Kern. The monthly mean is used so as to introduce a time element which would offset freak fluctuations which might occur in shorter periods.

The index for evaluating snowpack area is the same index used for evaluating snowpack runoff and is equal to the April mean flow of the Kern at Bakersfield. Naturally the long time interval of a month is necessary for this index, as it takes time for the river flow to reflect snowmelt produced by a fluctuating temperature. The long time interval again serves to average snowmelt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SAN JOAQUIN
KINGS
KAWEAH
KERN
ESTABLISHED SNOW COURSES
DRAINAGE BASIN BOUNDARIES
SCALE
MILES
CRESCENT CITY
YREKA
ALTURAS
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WEAVERVILLE
REDDING
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RED BLUFF
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OROVILLE
DOWNIEVILLE
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COLUSA
YUBA CITY
MARYSVILLE
NEVADA CITY
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STOCKTON
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MODESTO
REDWOOD CITY
MARIPOSA
MERCED
SAN JOSE
SANTA CRUZ
MADERA
HOLLISTER
FRESNO
INDEPENDENCE
SALINAS
HANFORD
VISALIA
Tulare Lake
Owens Lake
WHITE RIVER

Fig. 1--Drainage basins forecast by California Cooperative Snow Surveys, January, 1950

percentage losses which continually fluctuate.

The index for evaluating snowpack volume is the same as used in all computations by California Cooperative Snow Surveys, namely snowpack produced runoff occurring in the period April through July. In this step, however, no correction has been made for April precipitation, as in this watershed it is felt that most effective late precipitation comes to the higher areas of the basin in the form of snow. Again, temperatures are quite possible modified by such storms which offset the gain in runoff produced by the storm. Further ways to correct for this effect are contemplated, which, when found, may help to increase the accuracy of the relationship.

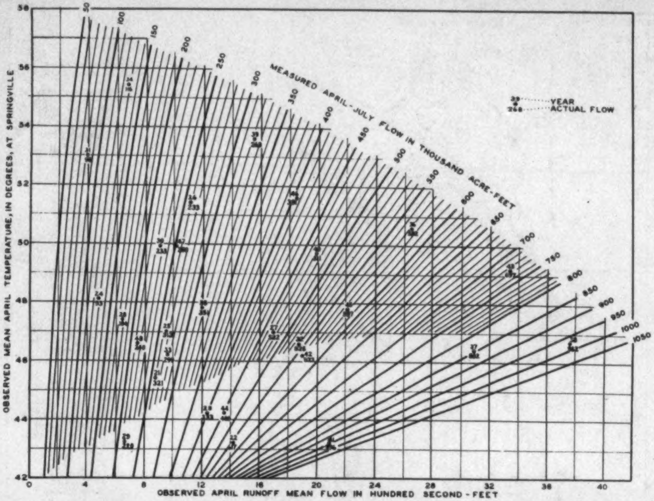


Fig. 2--Temperature-runoff diagram for the Kern River at Bakersfield

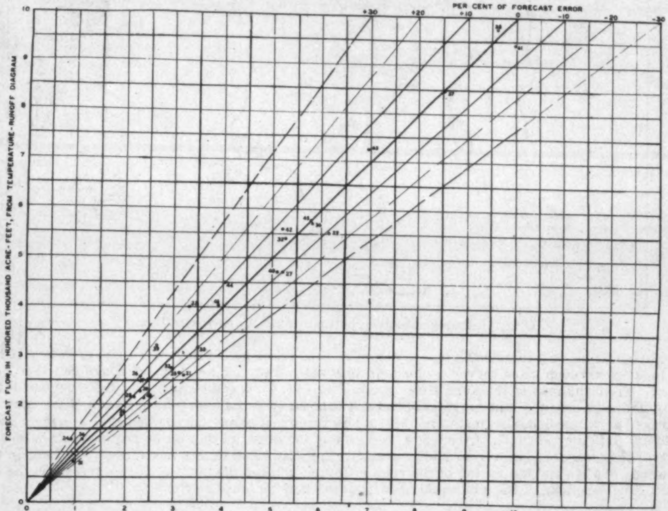
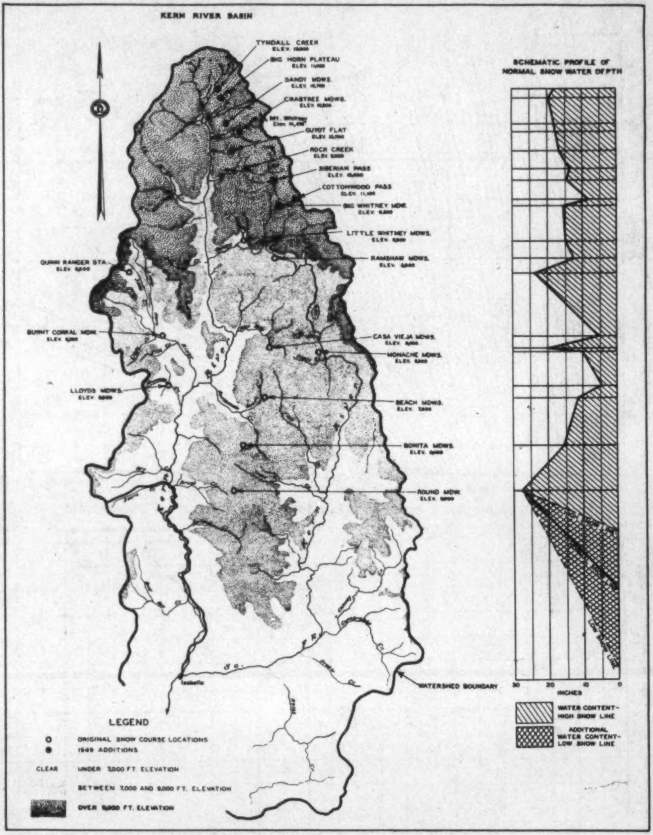


Fig. 3--Forecast accuracy from temperature-runoff diagram


KERN RIVER BASIN
TYNDALL CREEK
ELEV.
BIG HORN PLATEAU
ELEV.
SANDY MDWS.
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CRABTREE MDWS.
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Mt. Whitney
Elev.
GUYOT FLAT
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ROCK CREEK
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SIBERIAN PASS
ELEV.
COTTONWOOD PASS
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BIG WHITNEY MDW.
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LITTLE WHITNEY MDWS.
ELEV.
RAMSHAW MDWS.
ELEV.
QUINN RANGER STA.
ELEV.
BURNT CORRAL MDW.
ELEV.
CASA VIEJA MDWS.
ELEV.
MONACHE MDWS.
ELEV.
LLOYDS MDWS.
ELEV.
BEACH MDWS.
ELEV.
BONITA MDWS.
ELEV.
ROUND MDW.
ELEV.
Isabella
WATERSHED BOUNDARY
LEGEND
ORIGINAL SNOW COURSE LOCATIONS
1949 ADDITIONS
CLEAR
UNDER 7,000 FT. ELEVATION
BETWEEN 7,000 AND 9,000 FT. ELEVATION
OVER 9,000 FT. ELEVATION
SCHEMATIC PROFILE OF NORMAL SNOW WATER DEPTH
30
20
10
0
INCHES
WATER CONTENT-HIGH SNOW LINE
ADDITIONAL WATER CONTENT-LOW SNOW LINE
Low Snow Line

Fig. 4--Snowpack distribution for the Kern River Basin

It would be well to review steps which have been taken by California to increase the accuracy of forecast through snow survey methods in this watershed, and see how the above may then be used. From the map of the Kern River Basin (see Fig. 4), it can be seen that the location of the original snow courses laid out in 1930 had not touched upon the high plateau areas of the northern part of the watershed. Beginning in 1947, a new circuit of snow courses and shelter cabins was laid out in this upper area of the watershed so that the effect of this upper region could be evaluated when computing forecasts from snow surveys. Our last cabin in this new circuit was built in the summer of 1948 and the spring of the year following marked the start of snow surveys on the circuit. The locations of the additional snow courses may be found on the map.

It is still too early to know if these additional snow courses are the answer to our snow survey

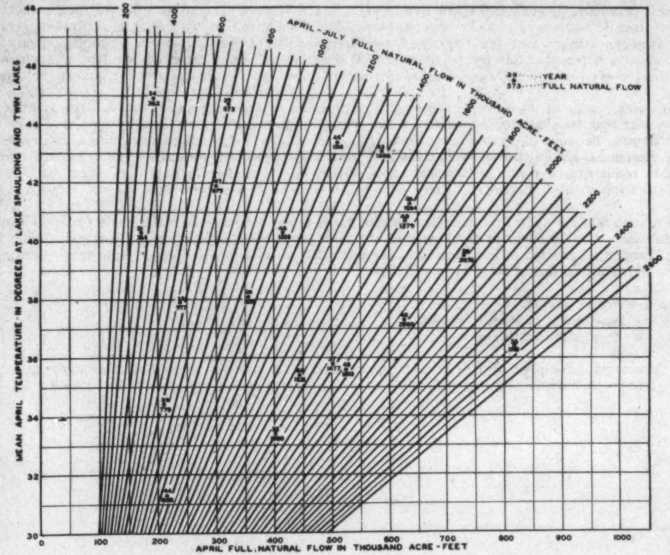

Fig. 5--Temperature-runoff diagram for American River at Fair Oaks

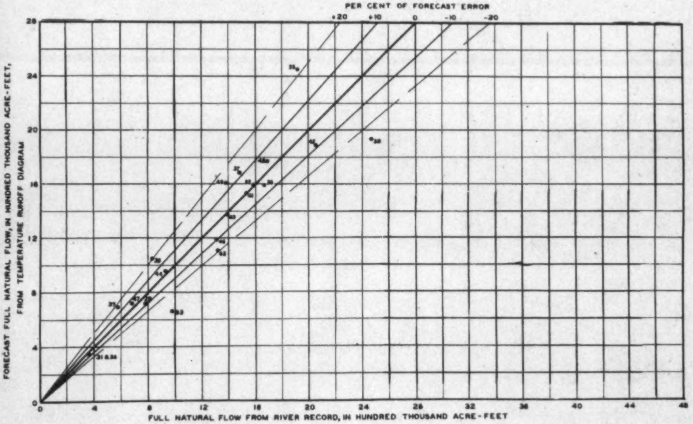

Fig. 6--Forecast accuracy from temperature-runoff diagram for American River at Fair Oaks forecast problem. It normally takes five to eight years of snow-course data before the characteristics of each snow course can be approximated. Until such time as we are able to forecast from snow surveys with greater accuracy, we intend to make use of our temperature-runoff diagram. We also have hopes that this temperature-runoff diagram will be of benefit in evaluating snowpack distribution even though snow surveys do ultimately produce forecasts of greater accuracy.

A quick glance at the snowpack-distribution diagram on Figure 4 shows that a large amount of snow water may be available because of a low snow line in a year which is figured to have normal water content because of snow course measurements. Conversely, a high snow line with a normal water year measured at the snow courses may produce appreciable smaller runoff. It is believed that this temperature-runoff relationship dove-tailed with snow-survey data may make possible the evaluation of this incremental water content in such abnormal snow line years.

Figures 5 and 6 show that accuracy in this basin is approximately on the same order as that for the Kern. Should our continued work on the Kern River give hopes of evaluating marginal water in the fluctuating portion of the snow line, further study will be made to interrelate this relationship to the other basins of the California area.

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THE FORMATION OF FRAZIL AND ANCHOR ICE IN COLD WATER

Vincent J. Schaefer

Abstract--Observations are presented concerning the formation of frazil and anchor ice under natural conditions and several methods are described for studying their physical properties. Photomicrographs show that the stable form of frazil ice is a thin, free-floating, rounded disk and that accumulations of these simple forms followed by regelation probably account for most of the underwater structures forming in bulk water supercooling to about -0.01° C. Frazil ice particles tend to gather on the upstream side of underwater objects with low adhesion between the collector and the ice mass.

Anchor ice forms as thin crystalline sheets firmly attached to underwater objects. Those observed were unlike frazil ice in appearance and general characteristics. A method is described for inducing the formation of frazil ice on a large scale by seeding supercooled water with small fragments of solid CO_2. Practical applications are suggested to determine whether this method may have economic importance wherever frazil ice causes trouble to hydroplants and similar installations in flowing streams which develop supercooling.

Introduction--Among the many and varied natural forms of ice, there are few more interesting than the forms of frazil and anchor ice which grow in cold flowing water. Despite the economic importance of these ice formations in the northern latitudes where they occur, there is a remarkable lack of basic information on the physical and crystalline properties of these forms. The work of BARNES [1926] contains one of the most detailed summaries of available data in this field. There seems to be a tendency more recently in books on hydrology to repeat these earlier reports, adding but little to the apparent gaps which seem to exist in our understanding of this phenomenon.

With greater attention currently directed to the more northern latitudes, problems involving frazil and anchor ice will probably become more common, since these formations occur wherever supercooled flowing water contacts cold air.

The occurrence of frazil ice--Frazil ice seems to occur whenever bulk water supercools. The degree of supercooling required, as shown by Barnes and confirmed by Granbois (personal communication), is rarely more than -0.01° C. The air temperature, however, must be considerably colder than 0° C. In an observation made by the writer at Pinkham Notch on the Cutler River in the open forebay of a small hydroelectric plant, a volume concentration of about 10^5 particles per cubic meter was observed with the temperature of the ambient air at -6° C. During this period the temperature was falling rapidly, the rapids above the pool were free of ice cover, and occasional light snow fell from thin clouds passing the summit of Mt. Washington upwind from the observation site.

It is possible that the particles observed in the water and on its surface were actually forming at a temperature considerably colder than -6° C, since near the headwaters of the stream about two miles up the mountain the air temperature was about -13° C. By immersing a half-inch mesh screen backed by one covered with fly screening, samples of the frazil ice particles moving underwater were obtained. Figure 1 is a photograph of this screen showing a collection of particles. The bright spots show single particles which are so oriented with respect to the illumination that they show specular reflection. It was found possible to make plastic replicas [SCHAEFER, 1941] of these particles by placing them on a glass plate cooled below freezing, letting the water drain from the samples, and then coating the icy residue with a cold solution of polyvinyl formal in ethylene dichloride.

The accumulation of frazil ice on underwater objects is well illustrated by Figure 2 which shows heavy underwater deposits observed by the writer in North Creek near the Hudson River during the winter of 1936. Similar deposits formed throughout the night along the Cutler River above and below the hydroelectric plant.

A concentration of frazil ice approaching $10^6/m^3$ was observed in February, 1950 on the Mohawk River with the air temperature about -20° C and a wind of three meters per second. At this

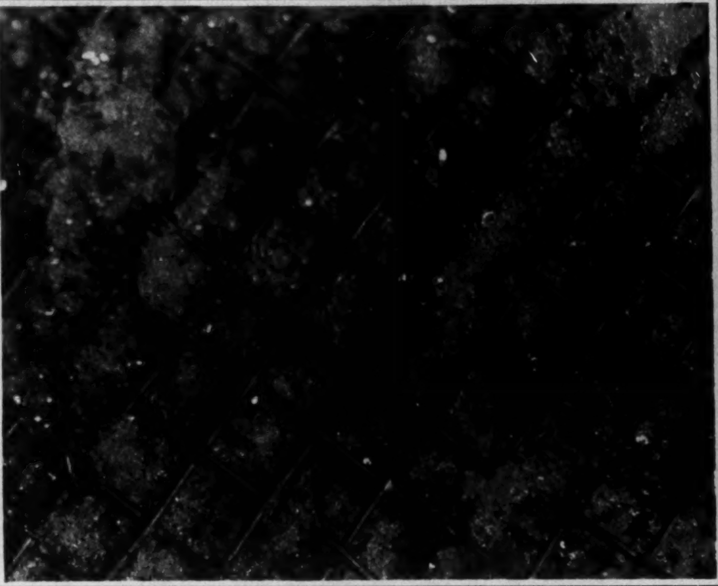

Fig. 1--Frazil-ice particles gathered on wire screening held underwater

time, at least 1000 m of the canal feeding the power house were free of ice cover.

The formation of frazil ice--Frazil ice is a free floating particle which in its early development is a thin circular disc showing no visible evidence of the trigonal symmetry so common to atmospheric snow crystals. Frequently, the particles are of irregular outline but although not symmetrical, the edges are invariably rounded as shown in Figures 3a and b. The initial formation of frazil seems to occur on the water surface. The particles may be seen forming small raft-like masses of floating skim ice. Wherever turbulence occurs, as in rapids or boils, many particles become submerged. When observed during active formation (best seen at night in a strong beam of light) the mass of water to a considerable depth exhibits myriads of scintillations due to specular reflections from the flat surfaces of the discs which tumble about underwater. Until the particles become two to three millimeters in diameter, it is rare to find secondary dendritic structures developing around the edges. Finally, such growths develop, the transitional stage shown in Figure 3c, and flat needle-like dendrites grow out from the edge of the flat discs to form structures similar in appearance to the stellar form of snow crystals. Subsequently, these dendritic growths break off to form needle-like fragments. As will be shown, such structures are apparently not the stable form of frazil ice, and it is quite likely that these fragments grow into the asymmetric rounded plates, such as may be seen among the collection shown in Figures 3a and b.

The thickness of frazil ice particles observed by the writer was in the range of 25 to 100 microns for particles 1000 to 5000 microns in diameter. It is probably this large ratio in major and minor axis and the small difference in specific gravity between ice and water which causes the particles to tumble about within the stream and, in many cases, to build up on underwater objects in a manner similar to that observed when falling leaves become water soaked and are carried underwater in a turbulent stream.

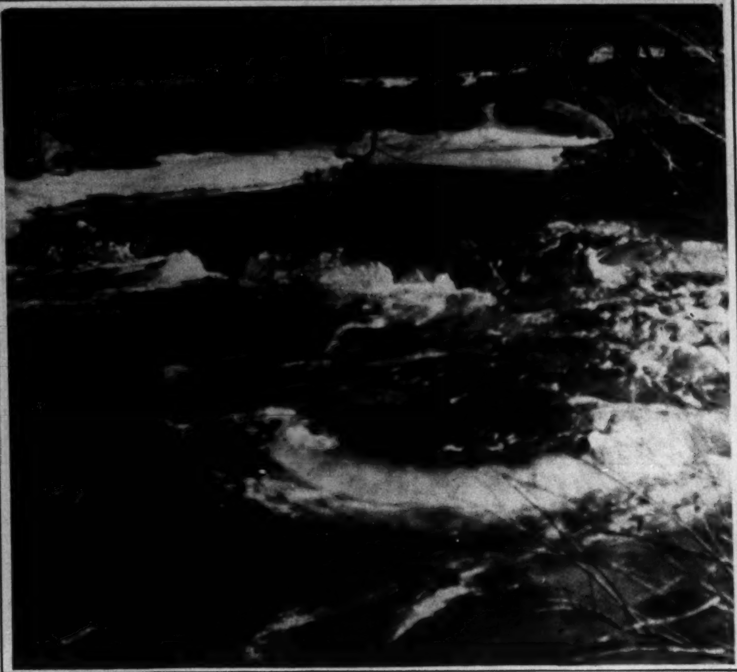

Fig. 2--Underwater accumulations of frazil ice in North Creek, N. Y.

The structures formed by deposits of frazil ice--An examination of the large sponge-like masses of frazil-ice particles which gather on rocks and other underwater objects shows that they consist principally of large numbers of particles like those illustrated in Figure 3. When examined *in situ*, many of the discs are seen edge on and appear to be fine needles. Particles showing dendritic growths are relatively uncommon.

When an object such as a chain, a series of vertical bars, or a wire screen, is submerged in water containing frazil-ice particles in suspension, a build-up occurs on their upstream side which is akin to the feather-like growth of rime on an airplane wing or similar structures on a mountain summit. These latter growths form from the impingement and freezing of supercooled cloud droplets on the upwind side of the collectors.

In the case of the trash racks at the intake of a hydroelectric generator system, the accumulation of frazil ice may be so rapid and the damming effect of the residue so marked that unless effective and continuing measures are employed to remove or prevent such build-ups the complete power generating system may be forced out of operation. Nothing is more dramatic than to witness a 30,000 KW hydro plant removed from the operating electrical network in less than an hour by the accumulation of these tiny frazil ice particles on the intake racks. Figure 4 illustrates the type of frazil ice deposits which forms on moveable trash racks and effectively stops the flow of water to the turbines. Such layers may form in 20 min. The bond between the 1/2-inch steel bars and the accumulated ice is relatively weak, since a strip 12 to 18 inches long may be pulled away from the bar by exerting a steady pressure from the side. Examination of this collection indicates it consists of a laminar buildup as shown in Figure 5. The flat surfaces are oriented at right angles to the direction of water flow and have a thickness considerably greater than would be produced by layering of the free floating primary frazil ice particles observed in the water passing the racks. The deposit was seen to grow out in the upstream direction and to fan out gradually in cross section until it joined with similar growths on the adjoining bars. The structure observed suggests that such deposits are due to a regelation produced by the merging of the small frazil ice particles cemented together by additional growth from supercooled water. Adhesion and capillary forces probably play an important role in the active formation of these shingle-like structures. Two flat solid surfaces separated by a thin water film have a remarkably strong affinity for each other, even though surrounded by water. Once brought into fairly close contact (the order of 0.1 to 0.5 microns) such objects resist separation, except by sidewise slippage.

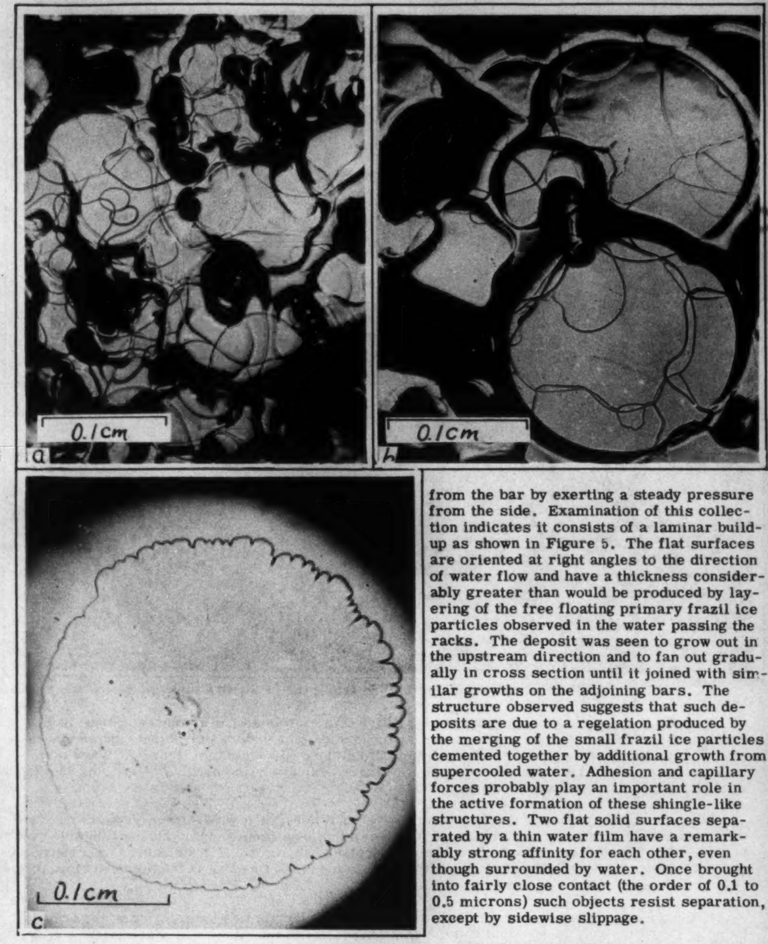

Fig. 3--Typical frazil-ice particles: (a) appearance of mass of frazil ice; (b) group of frazil-ice particles; and (c) single frazil-ice particle showing start of dendritic growths

The formation of anchor ice--Anchor ice consists of sheet-like crystals of ice which grow out from submerged objects in water. These formations are securely fastened to the objects on which they grow.

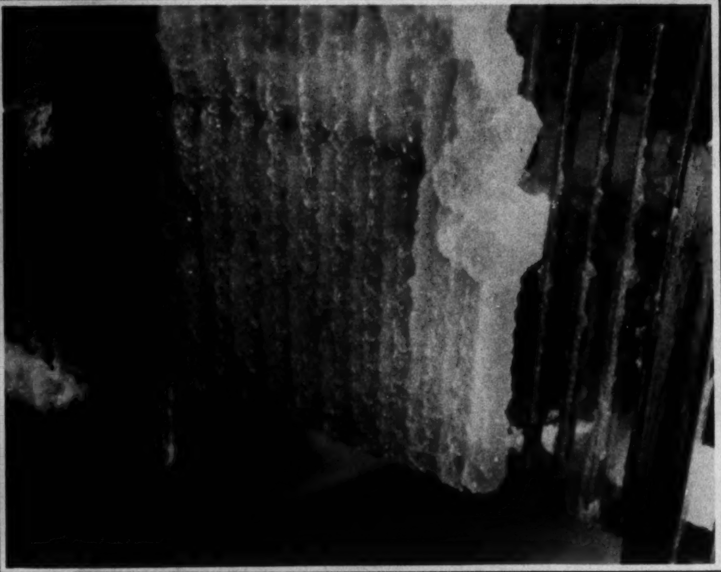

Fig. 4--Accumulation of frazil ice on moveable trash racks, School Street Station, Hudson Mohawk Power Corporation

It is obvious that in many cases a considerable amount of confusion exists between frazil and anchor ice. Frazil ice accumulations on submerged rocks and other objects may resemble anchor ice particularly when a secondary transformation occurs as shown in Figure 5. Although the specific gravity of all natural ice is less than unity, frazil ice particles may remain submerged indefinitely if the adhesion between their flat surfaces and an underwater collector is sufficiently great to overcome natural buoyancy. Too little observational data and physical measurements are available to confirm or dispute the theory of BARNES [1926] that anchor ice forms due to the radiational cooling of the stream bed. It should be possible to devise simple experiments to settle this point. The ice formations shown in Figure 6 are believed to represent a true example of anchor ice. These thin sheet crystals are typical examples of countless thousands found growing firmly attached to weeds along the Mohawk River flats after a sudden inundation by flood waters followed by an equally rapid recession during the winter of 1941.

Compared to the occurrence of frazil ice, anchor ice is a rarity in the experience of the writer. On the Cutler River at Pinkham Notch, New Hampshire where anchor ice was believed to occur rather frequently, a series of careful observations during the winter of 1949-1950 showed that some formations which had previously been called anchor ice were, in fact, structures produced by the shingling effect of frazil ice particles.

The stability of ice discs in cold water--Using a shallow tray filled by a small natural stream of water, it was possible to observe the initial stages and subsequent growth of frazil ice particles when the ambient air was colder than 0° C. At ambient temperatures warmer than -10° C, long ice needles always grew out from the edge of the tray and soon formed a solid sheet of ice on the water surface. At colder temperatures some frazil-ice particles were generally observed floating on the surface before the needles used up the supply of supercooled water. These appeared as thin rounded

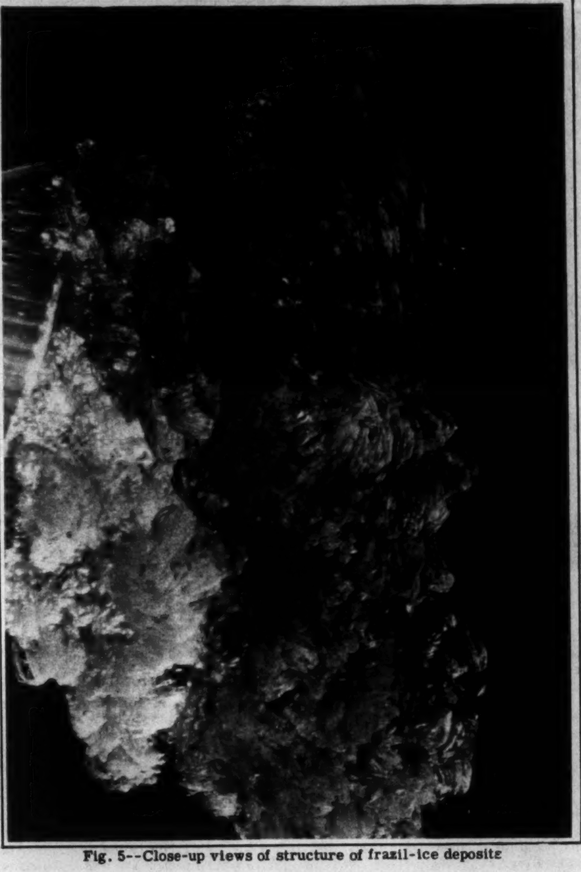

Fig. 5--Close-up views of structure of frazil-ice deposits

discs on the water surface and often showed a visible "mote" in their center. Foreign particles which serve as freezing nuclei [SMITH-JOHANNSEN, 1948] seem to possess properties different than those which are effective sublimation nuclei [SCHAEFER, 1949a]. The thickness of the water film must play an important role in determining the crystal habit, since hexagonal crystals commonly develop in very thin water films [SCHAEFER, 1949b].

Sometime ago, it was found [SMITH-JOHANNSEN, 1948] that a small piece of dry ice held close to a cooling mass of water, milk, or other watery substance provided an excellent means to determine the ice point of the substance. This seemed to be an effective way of studying the properties of frazil ice, since it is possible to initiate such formations whenever supercooling

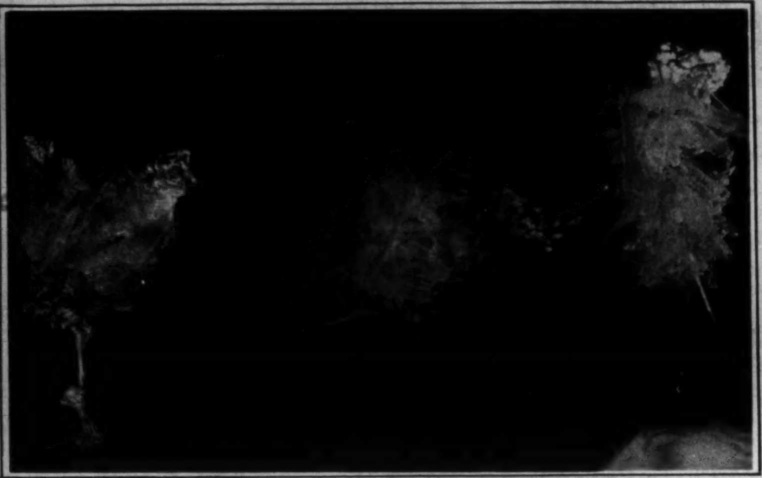

Fig. 6--Deposit of anchor ice growing on weeds

occurs regardless of ambient air temperature. Ice crystals formed by seeding bulk water grow in an unusual manner. Hexagonal columns produced by seeding with dry ice appear as shown in Figure 7a as they float on or slightly under a cold water surface.

Instead of continuing their angular development, however, the particles rapidly become rounded, while some of the smaller columns actually disappear as the more rounded particles grow in the near vicinity. This suggests that the disc-like frazil-ice particle is a more stable form of ice than the hexagonal form. Figure 7a, b, and c illustrates this transformation. The three areas outlined on each photomicrograph by dashed line circles show the growth and disappearance of certain particular particles at intervals of 60 sec, 120 sec, and 360 sec after seeding with dry ice. When the same type of observation was made using hexagonal plates for seeding, the transformations from angular to rounded form generally required less than five seconds, with many transformations requiring considerably less than one second.

The seeding of open water with dry ice to produce an ice cover--It is a common observation by persons concerned with the formation of frazil ice that whenever a layer of ice spreads over the water surface the formation of frazil ice ceases.

If it were possible to accelerate the formation of a continuous sheet of ice on a water surface by artificial means, it might be feasible to prevent the formation of frazil ice under some conditions. The first partially successful experiment along this line was carried out by the writer, assisted by Robert Temple, at Pinkham Notch, New Hampshire in December, 1949. Using liquid CO_2, it was found that the surface of the small forebay at the water intake could be rapidly coated with skim ice by seeding with ice crystals generated by the dry-ice snow formed by rapid expansion of the liquid. The presence of a long series of open rapids upstream which continually formed frazil ice crystals prevented a conclusive test of the method.

Subsequently, it was found by the writer that fragments of dry ice not larger than one gram in weight would not only float but were actively propelled by the evolution of gaseous CO_2 at the water-dry-ice interface. The vigorous motion of such floating particles in a free water surface is such that a considerable area of water is rapidly traversed by the scurrying particles. A one gram particle will exist for about three minutes on water at 0° C. There is a tendency for the dry-ice particles to become coated with a water-ice layer after a short time. This does not impair the

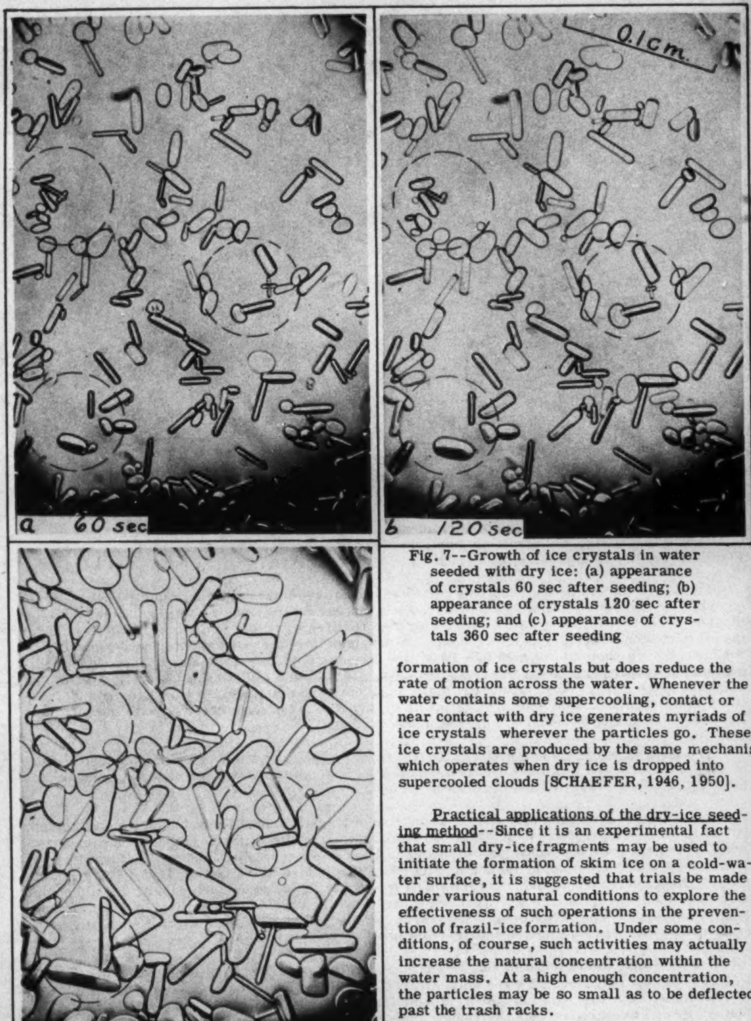

Fig. 7--Growth of ice crystals in water seeded with dry ice: (a) appearance of crystals 60 sec after seeding; (b) appearance of crystals 120 sec after seeding; and (c) appearance of crystals 360 sec after seeding

formation of ice crystals but does reduce the rate of motion across the water. Whenever the water contains some supercooling, contact or near contact with dry ice generates myriads of ice crystals wherever the particles go. These ice crystals are produced by the same mechanism which operates when dry ice is dropped into supercooled clouds [SCHAEFER, 1946, 1950].

Practical applications of the dry-ice seeding method--Since it is an experimental fact that small dry-ice fragments may be used to initiate the formation of skim ice on a cold-water surface, it is suggested that trials be made under various natural conditions to explore the effectiveness of such operations in the prevention of frazil-ice formation. Under some conditions, of course, such activities may actually increase the natural concentration within the water mass. At a high enough concentration, the particles may be so small as to be deflected past the trash racks.

Wave action, turbulence, and suction at the intake might limit the effective formation of an ice coating on the forebay. Dry ice is so inexpensive, however, that under some conditions it might even be feasible to seed the bay continuously so that skim ice forms wherever supercooling tends to develop.

Studies of the effectiveness of this process as related to supercooling should include, if possible, such information as air temperature, wind, cloud cover, turbulence, rate of water flow, water temperature, concentration of frazil-ice particles, type of build-up on underwater collectors, degree and type of ice cover on the water, and any other physical features which may have a bearing on the conditions of the observation and experiment.

Acknowledgments--The stimulating discussions and experimental observations made in cooperation with Joseph B. Dodge and Robert Temple of the Pinkham Notch Camp of the Appalachian Mountain Club were of considerable assistance in carrying out some of these studies. Thanks are also due to John Dillon of the Hudson Mohawk Power Corporation and to Bernard Vonnegut and Kiah Maynard of this laboratory who spent a cold night along the Mohawk studying frazil ice problems as related to a large hydroelectric plant.

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A COMPARISON OF NINE INDICES OF RAINFALL INTENSITY

Walter Dean Foster

Abstract--To supplement four frequently used, simple indices of rainfall intensity, namely, five-minute intensity, 15-min intensity, 30-min intensity, and average intensity (P/t), five compounded measures have been suggested. Through the use of appropriate statistical methods, these nine measures are compared for their relative merit in characterizing rainfall intensity.

Measures of rainfall intensity

Definition of rainfall intensity--It might be difficult to find a quantity which has been defined in more and different ways than rainfall intensity, each concept depending upon the use intended for it. Nevertheless, basic to every definition is the equation

$$P = \int_0^t i \, dt \quad \ldots\ldots (1)$$

where P is the total fall; i, the instantaneous rate of fall; and t, the time, which indicates the instantaneous nature of rainfall intensity. However, there are some restrictions to the usable form of the definition imposed by the nature of the recording mechanism of the two types of rain gages most commonly used in this country. Both the tipping-bucket gage and the weighing gage record rainfall in units of 0.01 inch, while a chronometer indicates the time necessary to acquire that unit of rainfall. The translation from chart to tabular form imposes another restriction on the data, the smallest unit of time being conveniently taken as one minute. Three examples of rainfall-intensity graphs are given in Figure 1, using HARROLD'S [1944] data. The question, how best to characterize a weather variable with a single, overall measure, is not a new one. Many scientists are dissatisfied with the characterization of daily temperature charts merely by a mean. Even so, analysis of weather records becomes exceedingly complicated unless some kind of single measure is adopted.

Four commonly used simple measures--Since the Weather Bureau in its Class A stations keeps a record of many measures of intensity (maximum amount of fall in 5, 10, 15, 20, 30, 45, 60 minutes, and so on, for every rain whose total fall exceeds 0.32 inch or whose rate of fall at any time exceeds 0.02 inch/min), it has been convenient to select one of these as an index to use. Popular in the literature have been I_5 (five-minute intensity), I_{15}, I_{30} and a fourth, I_{av}, defined as the total fall divided by the elapsed time. No choice in the definition of a storm period is offered in this study, since it was necessary to accept the rain period as that elapsed time over which concomitant measurements were taken in order to make the desired comparisons. It is our purpose here to compare these four simple parameters with five compound indices given later, for their relative adequacy in characterizing intensity.

Elements used in the construction of five compound parameters--With values which are readily available either from time-intensity graphs or tables, it is desired to construct parameters of rainfall intensity which will possess the following properties: (1) improved characterization of intensity; (2) ease of computation; and (3) universal application, with emphasis placed on property (1).

That any index of this kind should include a figure of peak intensity is obvious from a study of the time-intensity graphs. Since the maximum fall in 5, 15, and 30 min have been popular, let us start with

$$\pi = f(I_5\ ,\ I_{15}\ ,\ I_{30}) \quad \ldots\ldots (2)$$

where π = compound parameter of intensity.

It is apparent that each of the simple indices, the I_t, might be contained in a single large

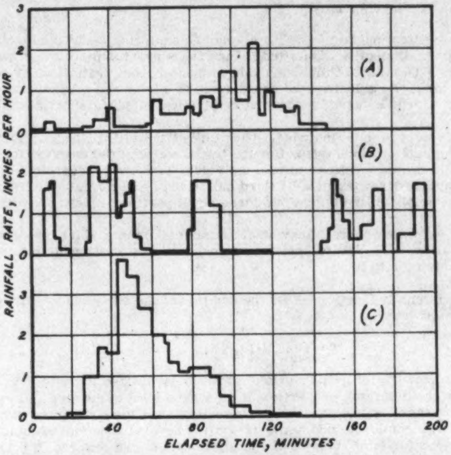

Fig. 1--Time-intensity graphs

burst, hence it is proposed to add a factor n, defined as the number of peaks exceeding one inch per hour, providing each peak is at least 30 min removed from a neighboring one. To explain why the definition specifies these particular restraints, it is necessary to digress momentarily into a discussion of infiltration.

Following the popular new concept described by COOK [1946] that runoff (soil loss is necessarily included) is a function of the rate of infiltration, it is assumed that any rainfall rate in excess of the infiltration rate will result in runoff. Depression storage, evaporation during rain, and interception would act to reduce the amount of runoff water. On the average, however, the effect of these factors is believed to be small, probably not greatly exceeding the error made in the regular measurement of rain totals and intensity. On the basis of data collected by FREE and Others [1940] from 68 soils representative of the major soil types found in the United States, average infiltration curves for both initial and wet runs were drawn (see Fig. 2). Note that beyond the first 30 min, the rate of infiltration is noticeably less on each curve than it was at any time during the initial 20 min. It should be apparent that the effect of any peak intensity of rainfall is greatest after an interval of time, taken here arbitrarily as 30 min. Study of the curve for the wet run reveals that the infiltration coordinate at time 30 min is very close to one inch, such that any excess in the rainfall rate could be considered as contributing to runoff. Since these are the minimum conditions for which, on the average, runoff will occur, they have been applied to the definition of n. For example, in Figure 1b, there are five peaks which exceed one inch per hour and are mutually separate by

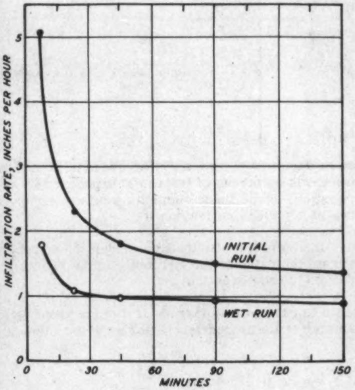

Fig. 2--Average rate of infiltration for 68 soils more than 30 min; thus, n = 5. In Figure 1c, n = 2. For storms which have no peaks exceeding one inch per hour, n is defined as unity.

In using the infiltration data to define n, any consideration of the compacting and sealing effects of raindrops on the soil was omitted. Since the apparatus used in estimating infiltration by FREE and Others [1940] did not include a rain simulator, their estimates of actual infiltration are undoubtedly high. By selecting the coordinates of n from the graph of the wet run instead of the initial run or a middle curve, we have attempted to compensate for this bias.

One more element is to be included. After an initial wetting, the soil surface admits less water; for a rain the bulk of which falls after the initial wetting, the contribution to runoff will be larger. A quantity b is now defined to take the values 1, 2, or 3, according as the greatest amount of rain falls within the first, second, or third half-hours. For rains which last longer than three half-hours, the time of fall is divided into three equal portions which follow the same convention.

There must exist, of course, many other possible elements which conceivably would add value to a compound parameter. Yet, to keep the computation to a reasonable minimum, the number of elements was restricted to five.

Form of the intensity function--With the addition of the two elements defined above, the estimating function is written

$$\pi = f(I_5\ ,\ I_{15}\ ,\ I_{30}\ ,\ b\ ,\ n) \qquad \ldots\ldots\ldots\ldots (3)$$

It now remains to find the functional form of these elements and to write it in usable form. To be conformable with the desirable properties, it must be a simple function and yet possess universal application. Since there appeared to be no rational method for writing the exact function of π, an intuitive method was employed, consisting of writing several functions so constructed as to offer certain comparisons for effectiveness of characterization. To this end, the following five models were set up

$$\left.\begin{aligned} \pi_1 &= I_{15}I_{30}(bn)^{1/3} \\ \pi_2 &= (I_{15} + I_{30})(bn)^{1/3} \\ \pi_3 &= I_{15}I_{30}(bn)^{1/2} \\ \pi_4 &= I_{15}I_{30}(n)^{1/2} \\ \pi_5 &= I_5I_{15}I_{30}(bn)^{1/3} \end{aligned}\right\} \qquad \ldots\ldots\ldots\ldots (4)$$

The values taken by b and n are large compared to the other terms, exerting undue influence on π, hence it was felt desirable to scale them downwards by means of fractional exponents so as to assign them a more appropriate weight in the equation. Since these elements (bn), are necessarily a weight, they have been included in the functions as a multiplicative factor.

Equations for π_1 and π_2 compare an additive model to a multiplicative model; π_1 and π_3 compare two fractional exponents; π_3 and π_4 investigate the value of the element b in the equation; π_5 investigates the possible improvement of adding I_5 to the equation.

These five compound parameters cannot begin to exhaust the possible list of functions to estimate intensity. For example, a compound parameter could be constructed of weighted elements, such as

$$\pi = k\ (I_5)^{a_1}\ (I_{15})^{a_2}\ (I_{30})^{a_3}\ (b)^{a_4}\ (n)^{a_5}$$

where the a's or weights are regression coefficients. Using the techniques in multiple regression, the elements which appeared to be relatively inefficient in this combination could be eliminated. In limiting the parameters to those listed in (4), it is hoped that a more extensive study might profit from the report on these five.

Criterion for comparison of intensity parameters

Selection by maximum correlation--In the absence of a true value of intensity, any index of intensity must be adjudged by the observed effects. These effects are runoff, soil loss, soil packing, degree of plant prostration, and similar factors, of which by far the greatest interest lies in runoff and soil loss. It is not proposed to say that the greater the runoff, the greater the intensity of the storm, for it can easily be seen that given two rains of equal intensity, the rain with the greater total amount is more likely to cause the greater runoff. However, given two rains with equal totals, the greater runoff is likely to be associated with the greater intensity, other factors being equal. We are thus led to state the principle by which the parameters are to be compared: that parameter which shows the maximum correlation with either runoff or soil loss or both after eliminating the effect of total rainfall, shall be selected as the best measure of intensity.

At this point, it might be objected that other factors such as initial soil moisture, vegetal cover, soil type, slope, conservation practices, and other factors, also affect runoff and soil loss, hence an accounting for these factors should also be included. Yet, it should be clear that these factors are relatively independent of rain intensity and total; for example, in non-mountainous areas, there is little likelihood that slope should be correlated with rain total or intensity beyond chance correlation. Assuming independence, then, it is obvious that accounting for these factors would not change the correlation between runoff and intensity.

It is our belief that the functional relationship between runoff and intensity can be sufficiently well approximated by a linear mathematical model to offer adequate comparisons among the various parameters of intensity. In addition, the linear model offers an extremely convenient method of removing the effect of total rainfall from consideration of intensity, as required by the criterion of maximum correlation. This is the familiar use of multiple regression. These models are written as

$$\left.\begin{aligned} W &= C + B_1P + B_2\pi + E \\ L &= c + b_1P + b_2\pi + e \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

where

W = runoff per storm, inches per acre
L = soil loss per storm, tons per acre
c, C = constants
b, B = partial regression coefficients
P = total rainfall
π = parameter of intensity
e, E = errors of estimation, NID $(0, \sigma_1^2, \sigma_2^2)$

The symbol W is used instead of the customary R, since the latter is reserved to denote the multiple correlation coefficient.

Method for evaluating parameters--Using the least-squares technique to fit these regressions, it is seen that maximum correlation is obtained for the predicting function when the sum of squares in the error term is a minimum, since in the identity

$$S(W - \overline{W})^2 = R^2\, S(W - \overline{W})^2 + (1 - R^2)\, S(W - \overline{W})^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where

$S(W - \overline{W})^2$ = sum of squares of runoff deviations
R^2 = multiple correlation coefficient
$R^2\, S(W - \overline{W})^2$ = sum of squares due to regression
$(1 - R^2)\, S(W - \overline{W})^2$ = error sum of squares

the smaller the sum of squares for error, the larger the value of R. Furthermore, since the effect of total rain P, is common to the regressions for all parameters of intensity, maximum correlation of intensity with runoff after accounting for P, is simultaneously obtained for a minimum error sum of squares.

Computationally, it has been easier to obtain the sum of squares due to the intensity parameter rather than to calculate R or the error sum of squares. Since this sum of squares due to the intensity parameter is directly related to R^2, nothing has been lost in estimating the relative merits of the different measures of intensity by this method.

Sources of data--Data with which to compare these nine parameters of intensity were taken from three separate experiment stations of the Soil Conservation Service: Statesville, North

Table 1--Sums of squares for intensity predictors for runoff

Parameters	Locations		
	Statesville	Shotwell	Naxwa[a]
π_1	1.9917	0.5700	
π_2	1.0188	0.6670	
π_3	1.6989	0.5447	
π_4	1.9230	0.5083	
π_5	2.0370	0.4323	
I_5	0.5198	0.2017	
I_{15}	1.2000	0.3746	
I_{30}	1.5400	0.8018	
I_{av}	1.2544	0.1835	

Table 2--Sums of squares for intensity predictors for soil loss

Parameters	Locations		
	Statesville	Shotwell	Naxwa
π_1	31.95	30.96	0.1544
π_2	33.68	24.83	0.1826
π_3	39.10	29.87	0.0705
π_4	28.32	30.95	0.0438
π_5	23.78	32.18	0.1258
I_5	3.91	14.09	0.0917
I_{15}	14.66	21.49	0.1621
I_{30}	14.04	20.68	0.1432
I_{av}	7.37	17.14	0.0875

[a] Since so many of these figures fell within the zone of rounding errors, apparently due to the fact that intensity was not at all well correlated with runoff, they were omitted from consideration.

Carolina; Shotwell, North Carolina; and Coshocton, Ohio. Records of runoff, soil loss, precipitation totals and intensity have been abstracted from published and unpublished data for this purpose. A brief description of each watershed follows.

At Statesville, the Watershed C-8, was an unterraced, cultivated field of predominantly Cecil clay loam with an average slope of seven per cent. Its 5.12 acres were sown to spring oats and lespedeza in 1933, lespedeza in 1934, cotton in 1935, soybeans and fall oats in 1936, and lespedeza in 1937 and 1938. Runoff was measured in a two-foot Parshall flume at the end of which a Ramser silt sampler determined the soil loss. Of the six years of data, 34 rains were selected for causing runoff and soil loss.

From Shotwell, all the rains occurring in 1941, and meeting the Weather Bureau's minimum requirements for intensity computation, were used. The data came from Station 5 which was planted to soybeans and had an average slope of two per cent. The 1/20 acre plot was equipped with a type-H flume to measure runoff and a Geib multislot divisor for soil loss. This land was predominantly Appling soil.

Watershed 123 of the North Appalachian Experimental Watershed (abbreviated for convenience in this paper to Naxwa) near Coshocton, Ohio, had an average 5.8 per cent slope over 1.4 acres of Keene silt loam. Planted in wheat for the year 1940, the basin's runoff was indicated by a measuring flume 2.5 ft deep while soil loss was given by a Ramser silt sampler.

Applying the models given in Eq. (5) to the data, the sums of squares due to each intensity parameter, adjusted for total fall, are given in Tables 1 and 2.

Statistical technique for comparison of intensity parameters

A cursory glance at the results in Tables 1 and 2 elicits three obvious conclusions. The use of I_5 to characterize the overall effect of intensity was the least effective of the nine studied. Almost as ineffective was I_{av} which made a very poor showing. The third fact is the consistency with which π_1 was near best in all cases. There exist several statistical techniques for the differentiation of these parameters with statements of probability to show the degree of differentiation. One such technique is given here briefly.

It is known that the dimensionality of the sum of squares for runoff is not the same as that for soil loss. Moreover, the magnitude of these values is hardly constant from location to location. To overcome these discrepancies, the parameters were ranked from one to nine to put them in more tractable from, although there is some loss of information in the transfer from scale to rank. These rankings are given in Table 3.

Use of normal deviates--An appropriate method in analysing ranked data, especially when the number of parameters is as large as nine and the number of ranks is five, is the analysis of variance on normal deviates. A normal deviate is defined by FISHER and YATES [1948] as

Table 3--Rankings of the nine parameters of intensity

Parameters	Statesville		Shotwell		Naxwa	Sum	Sum	Total
	W	L	W	L	L	W	L	W + L
π_1	2	3	3	2	3	5	8	13
π_2	8	2	2	5	1	10	8	18
π_3	4	1	4	4	8	8	13	21
π_4	3	4	5	3	9	8	16	24
π_5	1	5	6	1	5	7	11	18
I_5	9	9	8	9	6	17	24	41
I_{15}	7	6	7	6	2	14	14	28
I_{30}	5	7	1	7	4	6	18	24
I_{av}	6	8	9	8	7	15	23	38

$$u_r = \int_{-\infty}^{\infty} \left\{ n!/[(r-1)!(n-1)!] \right\} p^{n-r} q^{r-1} xz \, dx \quad \ldots\ldots\ldots\ldots (7)$$

where u_r = average deviate of r^{th} largest rank
z = ordinate of normal curve
p = probability of falling short of x
q = probability of exceeding x

Given a normally distributed population with unit variance, a sample of n observations is drawn (n = 9 in this problem). After the n observations have been ranked, the average, normalized deviate of each observation from the mean rank is given by u_r. The values of u_r have conveniently been tabulated by **FISHER** and **YATES** [1948]. The data in Table 3, transformed to normal deviates, are presented in Table 4.

Table 4--Rankings converted to normal deviates

Index	Statesville		Shotwell		Naxwa	Total
	W	L	W	L	L	
π_1	0.93	0.57	0.57	0.93	0.57	3.57
π_2	-0.93	0.93	0.93	0.0	1.49	2.42
π_3	0.27	1.49	0.27	0.27	-0.93	1.37
π_4	0.57	0.27	0.0	0.57	-1.49	-0.08
π_5	1.49	0.0	-0.27	1.49	0.0	2.71
I_5	-1.49	-1.49	-0.93	-1.49	-0.27	-5.67
I_{15}	-0.57	-0.27	-0.57	-0.27	0.93	-0.75
I_{30}	0.0	-0.57	1.49	-0.57	0.27	0.62
I_{av}	-0.27	-0.93	-1.49	-0.93	-0.57	-4.19

The analysis of variance using the normal deviates proceeds in a straightforward way, the total sum of squares being partitioned into two groups, between parameters and within parameters. Using the method given by COCHRAN and COX [1950] for examining individual degrees of freedom, six comparisons between the parameters taking two at a time were made, although it should be stated that these comparisons are not orthogonal. This analysis is given in Table 5.

Table 5--Analysis of variance on normal deviates

Source	Degrees of freedom		Sum of squares	Mean square	Probability
	Comparisons	Orthogonal			
Between parameters		8	15.6961	1.9620	a
π_1 versus π_3	1	...	0.4840	0.4840	NS[b]
I_5 versus I_{30}	1	...	3.9600	3.9600	a
I_{av} versus I_{30}	1	...	2.3100	2.3100	c
π_1 versus I_{15}	1	...	1.8660	1.8660	near 8 pct
I_5 versus I_{15}	1	...	2.4210	2.4210	c
π_1 versus π_4	1	...	1.3320	1.3320	near 13 pct
Within parameters	..	36	19.1319	0.5312	....
Total	..	44	34.8280	....	....

[a] Significant at one per cent.
[b] NS means not significant.
[c] Significant at five per cent.

Conclusions

From the individual comparisons, it is seen that I_{15} is without doubt a better index of intensity than I_5, while I_{15} itself is surpassed by π_1 at a significance level near eight per cent. That the best simple index for intensity is I_{30} is indicated by its comparisons with I_5 and I_{av} together with its slightly better overall showing than I_{15}.

Of the compound indices, there are no clearly defined differences except as shown by the acceptable (probability less than 0.20) superiority of π_1 over π_4. The most easily computed index in the compound group, π_4, offers some evidence of the value of the element b which was not included in π_4. The evaluation of π_5 involved more factors than any other index, yet proved to be no better than some others, hence π_5 also is not recommended. Of the compound group, we are left with π_1, π_2, and π_3 from which to choose a best index, although on the basis of the experimental evidence and statistical treatment, none might be chosen with impunity. Nevertheless, because of its consistency from trial to trial in addition to its highest overall ranking, π_1 would seem to be the best of the compound group.

These data do not offer conclusive evidence that π_1 is unquestionably superior to I_{30}. There is, however, considerable reason to believe that a compound index can be constructed from readily available information, which provides a better characterization of rainfall intensity than any of the commonly used simple indices.

These parameters tended strongly to take the same relative position in the rankings for both runoff and soil loss, substantiating the *a priori* reasoning for summing the ranks over both effects.

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THE PROBLEM OF MOUNTAIN CHAINS

W. S. Jardetzky

Abstract--In order to explain the formation of ranges of mountains on the Earth's surface, the solution of three following fundamental problems must be given: (1) the mechanism of the folding of a mountain range, (2) the field of forces corresponding to an actual simultaneous distribution of mountain ranges, and (3) the changes of this field during the geological history. Four principal types of the mechanism of folding may be discerned. The hypothesis of the zonal rotation of the Earth leads to the distribution of forces in the crust which can produce the mountain building in the Tertiary. A certain variation of this field of forces in the preceding geological periods may be established.

General remarks--For the formation of ranges of mountains on the Earth's surface we do not yet possess a theory which would be able to explain all known facts. Moreover, the controversy among different viewpoints concerning this process is intimately connected with the impossibility of reconciling contradictory statements about the dynamics of the Earth's crust in general. It is obvious that orogeny being only one phenomenon among other fundamental phenomena occurring during the Earth's evolution may be understood, if we give a clear conception of the latter. But the principal difficulty and the reason for failure of the well-known theories is that, taking into account one important factor in its most general form (for example, cooling of the Earth, convective currents), a theory attempts to show that only this factor can explain the structure of the Earth's upper layers. However, it is often not difficult to see that such a factor alone fails to explain the real distribution of all main features on the Earth's surface. Thus, the shrinkage of the Earth or intensive convective currents could probably produce some mountain ranges, but on assuming the effectiveness of one of these factors nobody was able to answer the fundamental question, "Why do the mountain ranges have their actual positions and not some other?"

It is not the scope of this paper to criticize the theories of mountain-building. The writer has already given a detailed discussion of the subject [JARDETZKY, 1948a]. Our knowledge about the structure of the Earth seems to be advanced sufficiently that an analysis of the importance of each principal factor is possible. To make this analysis more systematic all the questions connected with the problem of mountain building should be divided in three groups: (1) the questions concerning the mechanism of the formation of a mountain range; (2) the distribution of forces acting in the Earth's crust through a given geological period and producing the simultaneous formation of the ranges in different parts of the crust; and (3) the changes of such a field of forces during the geological history.

Principal types of mechanisms of the mountain ranges--On considering now only the process of formation of the mountain ranges we have to deal with the fundamental fact, namely, that every range is a part of a compressed strip of the Earth's crust. In general this strip is formed by several horizontal layers and is curved by the action of mechanical forces. We shall avoid the misleading term orogenic forces and speak about the external causes or forces (such as gravity), for example, applied on the boundary surfaces and producing a stressed state in the strip. This state is determined by a system of normal and shearing stresses acting in a body and depending on the properties of the material. It is this system of internal forces which produces the corresponding deformation of the body. But a stressed state favorable to the formation of a mountain range may be caused by different factors. Many models have been invented to show the mechanism of mountain building. A few examples are the classical experiments of WILLIS [1893], the recent ones of KUENEN [1936], VENING MEINESZ [1948], and of GRIGGS [1939]. The last experiments were especially important since they satisfied the conditions of the dynamic similarity. Based on quite different principles all the models reproduce the characteristic property of the mountain building, namely, the folding of a certain region of the body. While in one set of experiments this folding is caused by a pure compression of a plastic material, in the experiments of Griggs the folding results from the existence of the tangential stresses on the bottom boundary of a layer supported by a moving liquid. Thus, in both systems of external forces the normal stresses acting in the plan of the strip and the tangential stresses along its bottom boundary may produce the same effect, folding, and we shall see further that this phenomenon is probably caused in some mountain chains by a pressure, with or without shear, and in others by external tangential forces.

In every case we must establish which other factors are involved with these forces in the process of formation of a mountain range, since the mere existence of these forces is not a sufficient condition for the beginning of the process. If we assume that the material forming the upper layers of the crust possesses the properties of an elastic body, the first effect of a pressure acting on the lateral faces of a strip or of a spherical shell could be perhaps a bending of such a part of the crust (if it is thin enough to allow the deformation of this kind). PREY [1942] has computed the bending of a spherical shell having dimensions of a small round continent and subjected to the hydrostatic pressure produced by a fluid substratum on which the continent floats. It seems to the writer that the bending of such a large part of the Earth's crust may be connected with the epeirogenesy in some cases, since the last phenomenon can be in other cases a consequence of a deformation of the whole Earth or of a local deformation produced by forces of some other kind. The small wavelength of the bent strata we have in the mountain ranges can hardly be understood, if the bending of a larger part of the crust takes place, since the bending caused by the hydrostatic pressure will be connected with a contraction of the bottom layers of the crust and tension in the upper layers. (The opposite distribution of forces is also possible and happens when a deformation of some part of the Earth's crust is connected with a flattening of the spherical shell.) The variety of conditions under which all the mountain ranges were formed on the Earth's surface may be very great. But it seems that we can discern four following typical cases: (1) Pre-Cambrian; (2) coastal; (3) intercontinental; and (4) the type of Himalaya (which in one sense is also intercontinental).

The Pre-Cambrian type--In the earliest period of formation of the Earth's crust, when the floating blocks could be pushed one against the other by some currents in the fluid substratum, there were always conditions favorable to the folding of the thin upper layers. The convective currents, or currents of some other kind, could hinder the formation of the continuous crust during a longer time and produce folding over large areas by tangential stresses on their bottom faces. This kind of folding could be continued in a thin crust of the earlier Pre-Cambrian.

Many investigations of the deformations of plates and shells have been carried out and BIJLAARD [1946, 1947, 1948] has recently given a theory of folding of a thin plate supported by a semi-infinite layer of substratum, which may be applied to the deformations of the young Earth's crust. The main result of this theory is that a plate can buckle in waves perpendicular to the direction of the compressive force. Currents of every kind in the substratum would be able to produce the folding in a sufficiently thin crust, but the writer has suggested the importance of the hypothesis of the zonal rotation of the Earth [JARDETZKY, 1935, 1948a, 1948b]. It was shown that, if the zonal currents occur in a hollow sphere filled up with a liquid, the tangential stresses on the inner side of the spherical shell may provoke its rupture along curves belonging to a certain family. But there is another family of curves orthogonal to the first, and having directions favorable to the folding [JARDETZKY, 1948a, p. 10]. Some experiments, the principal aim of which was to show the formation of continents, also gave material concerning mountain building.

If we assume that a rectangular plate, whose thin upper layer is solid and the bottom layer plastic, is at the bottom face subjected to tangential forces distributed according to the law of a zonal rotation (the velocity $v = a - by^2$ where y is the distance from the equatorial line and a and b are two positive constants) this plate will be deformed in a manner represented in Figure 1. The folds are distributed in a regular way and form an angle of ± 135° with the line of the maximum displacement. (The material used was the dough dried on its upper surface. The zonal motion was produced by a special apparatus [JARDETZKY, 1948a, 1948b].) It remains an open question, whether the folds produced by this or a similar process have dimensions comparable with those of mountain chains. These folds could be small undulations.

If, during the earlier geological periods, sets of mountain ranges were really formed simultaneously over large areas by the understreaming substratum or by the gliding of these parts of the crust, we could call them the Pre-Cambrian type. But during the later geological periods, when the crust had thickened, the conditions of forming similar folds became less favorable and even unfavorable.

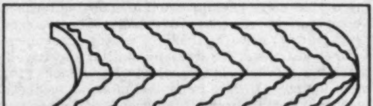
Fig. 1--Pre-Cambrian type of mountain building

The special distribution of velocities in a fluid substratum, which we called a zonal movement, is not a necessary condition of the forming of mountain ranges. But we shall see its importance when discussing the positions of the mountain ranges on the Earth's surface. We can now leave out of consideration this special distribution of velocities and proceed with the analysis of the question, in what manner a current in the substratum might be favorable to the formation of a mountain range on a supported continent. The simplest cases are those in which a continent is pushed against some other part of the crust or inversely when a solidified bottom of an ocean is forced by traction to press on the continent or, finally, when the lateral faces of a continent are subjected to the pressure of the fluid substratum. In all these cases we may expect the formation of coastal mountain ranges parallel to the seashore. But the continents were never homogeneous blocks. Their oldest and strongest parts are shields, between which could lie geosynclines, the weaker strips in the crust. If now by some distribution of velocities in the substratum one shield is pushed against the other, the strip separating them will be pressed on both sides and we have conditions favorable to formation of an intercontinental mountain chain. The form of the ridge will then be conditioned by the form of that strip. If the borders of a strip were parallel straight lines, the formation of folds parallel to these lines might be expected. But there are more complicated cases, for example, when a shield having the form of a polygon is pushed against the principal part of a continent in the direction of one angle (as a square in the direction of its diagonal). It is obvious that the formation of a broken mountain range along the sides of the angle running into the continent is then probable. This seems to be the case of Himalaya.

The coastal mountain ranges--The principal difficulty we meet, when the problem of formation of a mountain range is to be posed in its mechanical form, consists in the behaviour of the real material, since neither crystallized matter nor layers of sediments possess properties of some definite ideal body exclusively. In order to get the first approximation, it is generally acceptable to follow Darwin's idea, to make use of the equations of the theory of elasticity and, after the deformation of a body is computed, to replace the displacements by the velocities of particles. It is very probable that the qualitative results thus obtained will not differ much from the true picture. The other difficulty is of a mathematical nature and in order to find the solution of the equations of the problem the simplest schemes and elementary methods of analysis are used.

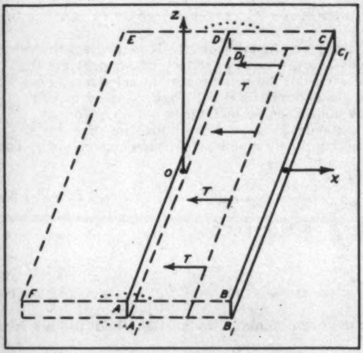

Fig. 2--Formation of a coastal mountain range

Since we want to find now the conditions of formation of a coastal mountain range, we will consider a strip which is dragged against another body (see Fig. 2). To simplify the problem we assume that the deformation of the strip corresponds to a plane strain. The known solutions of the theory of plates are usually given in a form which makes easy the computation of the bending, but it is more important in our problem to know what happens in the neighborhood of the borders.

Figure 2 represents a moderately thick strip AC_1 of an isotropic and homogeneous material. Its thickness we denote by 2h and the width by a. If we consider the plane strain in the plane Oxz, the displacements u and w of a particle will be solutions of

$$\left.\begin{aligned}\nabla^2 u + [(\lambda+\mu)/\mu]\,\partial\theta/\partial x = 0\\ \nabla^2 w + [(\lambda+\mu)/\mu]\,\partial\theta/\partial z = 0\end{aligned}\right\}\quad\ldots\ldots\ldots(1)$$

where $\nabla^2 = \partial^2/\partial x^2 + \partial^2/\partial z^2$ and

$$\theta = \partial u/\partial x + \partial w/\partial z \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

These solutions may be written in the form

$$u = -[(\lambda+\mu)/2\mu]\,x\theta + \phi_1\;,\quad w = -[(\lambda+\mu)/2\mu]\,z\theta + \phi_3 \quad\ldots\ldots\ldots \quad (3)$$

and $\theta\,(x,z)$, $\phi_1(x,z)$ and $\phi_3(x,z)$ are harmonic functions ($\nabla^2\theta = 0$, $\nabla^2\phi_1 = 0$, $\nabla^2\phi_3 = 0$). On inserting (3) in (2) we obtain the relation

$$[(\lambda+2\mu)/\mu]\,\theta = -[(\lambda+\mu)/2\mu](x\,\partial\theta/\partial x + z\,\partial\theta/\partial z) + \partial\phi_1/\partial x + \partial\phi_3/\partial z \quad\ldots\ldots\;(4)$$

The stress-strain relations are

$$X_x = \lambda\theta + 2\mu \partial u/\partial x , \quad X_z = \mu(\partial u/\partial z + \partial w/\partial x) \quad , \quad Z_z = \lambda\theta + 2\mu \partial w/\partial z \; \ldots\ldots \; (5)$$

and the fourth stress Y_y which is necessary to maintain the state of a plane strain may be computed, when u and w are determined. The general solution of the Laplace equation $\nabla^2\theta = 0$ is

$$\theta = A_o + \sum_{n=1}^{\infty} [A_n(x + iz)^n + B_n(x - iz)^n]$$

(See, for example, LOVE [1934].)

If P_n and Q_n denote the harmonic polynomials, $P_n + iQ_n = (x + iz)^n$, we may write the general solution of the Laplace equation also in the form

$$\theta = a_o + \sum_{n=1}^{\infty} (a_n P_n + b_n Q_n) \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (6)$$

This solution is regular at the origin and the series (6) will be convergent in general in some region, $x^2 + z^2 = r^2 < R^2$. Since the harmonic functions ϕ_1 and ϕ_3 may be represented by similar series, we obtain from (3), (6) and two similar equations

$$\left.\begin{aligned} u &= -[(\lambda + \mu)/2\mu]\, x[a_o + \Sigma(a_n P_n + b_n Q_n)] + \alpha_o + \Sigma(\alpha_n P_n + \beta_n Q_n) \\ w &= -[(\lambda + \mu)/2\mu]\, z[a_o + \Sigma(a_n P_n + b_n Q_n)] + \gamma_o + \Sigma(\gamma_n P_n + \delta_n Q_n) \end{aligned}\right\} \ldots . \; (7)$$

The coefficients a_o, a_n, ... must have such values as to satisfy the boundary conditions: $X_n = X_x \cos(xn) + X_y \cos(yn) + X_z \cos(zn)$, $Y_n = \ldots .$, $Z_n = \ldots .$ On the faces $z = \pm h$ of the strip only $\cos(zn) = \pm 1$ is different from zero. Therefore the boundary conditions are

$$\pm\mu(\partial u/\partial z + \partial w/\partial x) = X_n , \quad \pm(\lambda\theta + 2\mu\, \partial w/\partial z) = Z_n , \quad \text{for } z = \pm h \; \ldots\ldots\ldots . \; (8)$$

and the boundary stresses $X_n = X_n(x)$, $Z_n = Z_n(x)$ are given functions of x. If we neglect the possible displacement of the whole system (strip and obstacle), we can introduce in our problem the condition of symmetry on assuming that two equal strips of the same material are dragged one against the other. The first consequence of these assumptions is that X_n and Z_n must be odd functions of x. Further we may give now the same conditions on both faces $x = \pm a$. We may assume, for example, that X_x = a given function of z and $Z_x = X_z$ = a given function of z, for $x = \pm a$ or that w is a given function of z for $x = \pm a$. Thus, if we consider a strip connected with two shields we could assume that

$$(W)_{x = \pm a} = 0 \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (9)$$

The same approximation would be possible for free faces of a very wide strip.

Finally, the conditions of symmetry are

$$u(-x, z) = -u(x, z) \quad , \quad w(-x, z) = w(x, z) \; \ldots\ldots\ldots\ldots\ldots \; (10)$$

Equation (4) implies a set of relations connecting the coefficients of the series (7). It follows from $P_n + iQ_n = (x + iz)^n$ that

$$\partial P_n/\partial x = \partial Q_n/\partial z = nP_{n-1} \quad , \quad \partial P_n/\partial z = -\partial Q_n/\partial x = -nQ_{n-1} \; \ldots . \; (11)$$

(Cauchy-Riemann's equations) and, since P_n and Q_n are homogeneous polynomials, then

$$x\, \partial\theta/\partial x + z\, \partial\theta/\partial z = \sum_1^{\infty} n(a_n P_n + b_n Q_n) \; \ldots\ldots\ldots\ldots \; (12)$$

On substituting (6) and similar expressions for ϕ_1 and ϕ_3 in (4) and taking into account (11) and (12) we obtain

$$\begin{aligned} &[(\lambda + 2\mu)/\mu][a_o + \sum_1^{\infty} (a_n P_n + b_n Q_n)] = -[(\lambda + \mu)/2\mu] \sum_1^{\infty} n(a_n P_n + b_n Q_n) + \\ &\quad + \sum_1^{\infty} n(\alpha_n P_{n-1} + \beta_n Q_{n-1}) + \sum_1^{\infty} n(-\gamma_n Q_{n-1} + \sigma_n P_{n-1}) \; \ldots\ldots\ldots\ldots \; (13) \end{aligned}$$

Since $P_o = 1$, $Q_o = 0$, we obtain, on putting equal the coefficients of the same harmonic on different sides of (13)

$$\left.\begin{aligned}[(2+n)\lambda + (4+n)\mu]a_n/2\mu &= (n+1)\alpha_{n+1} + (n+1)\delta_{n+1}\\ [(2+n)\lambda + (4+n)\mu]b_n/2\mu &= (n+1)\beta_{n+1} - (n+1)\gamma_{n+1}\end{aligned}\right\}\ldots\ldots\ldots\ldots(14)$$

The first relation holds for $n = 0, 1, 2, \ldots.$ Inserting (7) in (8), the four boundary conditions for $z = \pm h$ take the form

$$\left.\begin{aligned}&\pm\mu\Big\{-[(\lambda+\mu)/2\mu]x\,\Sigma n(-a_n Q_{n-1} + b_n P_{n-1}) + \Sigma n(-\alpha_n Q_{n-1} + \beta_n P_{n-1})\\ &\qquad - [(\lambda+\mu)/2\mu]z\,\Sigma n(a_n P_{n-1} + b_n Q_{n-1}) + \Sigma n(\gamma_n P_{n-1} + \delta_n Q_{n-1})\Big\}_{z=\pm h} = X_n\\ &\pm[-\mu\Big\{a_o + \Sigma(a_n P_n + b_n Q_n)\Big\} - (\lambda+\mu)z\,\Sigma n(-a_n Q_{n-1} + b_n P_{n-1})\\ &\qquad + 2\mu\Sigma n(-\gamma_n Q_{n-1} + \delta_n P_{n-1})]_{z=\pm h} = Z_n\end{aligned}\right\}(15)$$

In general X_n and Z_n may be expanded in power series

$$X_n = \Sigma T_n x^n, \qquad Z_n = \Sigma S_n x^n \qquad \text{for } z = -h \ldots\ldots\ldots\ldots (16)$$

and similar series for $z = +h$. Since we do not take now into account the hydrostatic pressure on the bottom face of the strip we put $Z_n = 0$ for $z = +h$. We assume now that the terms on the left side of (15) may be rearranged in order to form a power series in x and comparing it with the series (16) we obtain the new relations between the coefficients a_n, b_n, α_n, β_n, γ_n, and δ_n. But T_n will be then given as an infinite series composed of these coefficients. The same difficulty will arise, if we substitute (7) into boundary conditions (9) or $X_x = f(z)$ for $x = \pm a$. But we may proceed by successive approximations and take a finite number of terms in (7). Then all other relations will be composed of a finite number of coefficients and it will be possible to compute them.

We shall now assume that we may neglect the terms of the fourth and higher order in (7). Then, on writing the polynomial P_n and Q_n, we obtain

$$\left.\begin{aligned}u = &-[(\lambda+\mu)/2\mu]x\,[a_o + a_1x + b_1z + a_2(x^2 - z^2) + 2b_2xz] + \alpha_o + \alpha_1x + \beta_1z\\ &+ \alpha_2(x^2 - z^2) + 2\beta_2xz + \alpha_3(x^3 - 3xz^2) + \beta_3(3x^2z - z^3)\\ w = &-[(\lambda+\mu)/2\mu]z\,[a_o + a_1x + b_1z + a_2(x^2 - z^2) + 2b_2xz] + \gamma_o + \gamma_1x + \delta_1z\\ &+ \gamma_2(x^2 - z^2) + 2\delta_2xz + \gamma_3(x^3 - 3xz^2) + \delta_3(3x^2z - z^3)\end{aligned}\right\}\ldots\ldots\ldots(17)$$

Taking into account (10) we put

$$a_1 = b_2 = \alpha_o = \beta_1 = \alpha_2 = \beta_3 = \gamma_1 = \delta_2 = \gamma_3 = 0 \ldots\ldots\ldots\ldots (18)$$

We will first consider a solution which is also symmetric in z since we take a symmetric distribution of tangential stresses on both faces $z = \pm h$. Although this solution does not correspond to some principal type of deformation of the Earth's crust, it may present a certain interest on showing one general characteristic property. Thus we assume that

$$u(x, -z) = u(x, z), \qquad w(x, -z) = -w(x, z) \ldots\ldots\ldots\ldots (19)$$

Then, the coefficients b_1, β_2, γ_o, and γ_2 must also vanish and (17) take the form

$$\left.\begin{aligned}u &= -[(\lambda+\mu)/2\mu]x\,[a_o + a_2(x^2 - z^2)] + \alpha_1x + \alpha_3(x^3 - 3xz^2)\\ w &= -[(\lambda+\mu)/2\mu]z\,[a_o + a_2(x^2 - z^2)] + \delta_1z + \delta_3(3x^2z - z^3)\end{aligned}\right\}\ldots\ldots\ldots(20)$$

These expressions being given, the coefficients $a_o, \alpha_1, \ldots.$ must satisfy two following equations, since the other relations (14) become identities,

$$[(\lambda + 2\mu)/\mu]a_o = \alpha_1 + \delta_1, \qquad [(2\lambda + 3\mu)/\mu]a_2 = 3\alpha_3 + 3\delta_3 \ldots\ldots\ldots (14')$$

It follows from the first of (15) or (8) and (20), if we put $X_n = T_1x$ (see (16)), that

$$6\mu(\delta_3 - \alpha_3)h = T_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

and from the second of (15)

$$-a_2 + 6\delta_3 = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

$$-\mu a_o + (2\lambda + 3\mu)a_2h^2 + 2\mu\delta_1 - 6\mu\delta_3h^2 = 0 \ldots\ldots\ldots\ldots\ldots (23)$$

Solving the group of equations for a_2, α_3, and δ_3 we obtain

$$a_2 = -T_1/4h(\lambda + \mu)\ , \qquad \alpha_3 = -(4\lambda + 5\mu)T_1/24h\mu(\lambda + \mu)\ , \ \delta_3 = -T_1/24h(\lambda + \mu) \ldots (24)$$

Eq. (23) may be simplified by using (24). It is

$$-\mu a_o + 2\mu\delta_1 = hT_1/2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (23')$$

The boundary conditions on the faces $x = \pm a$ may be given in different forms, as mentioned above, but it is rather difficult to suppose that the displacements of all points on these faces are equal to zero. To avoid this difficulty and a mathematical one connected with it, we assume that only the principal aprt of w, that is, the coefficient of z, vanishes on the faces $x = \pm a$. Putting now

$$-[(\lambda + \mu)/2\mu][a_o + a_2a^2] + \delta_1 + 3\delta_3a^2 = 0$$

and substituting the expressions (24) we obtain

$$-(\lambda + \mu)a_o + 2\mu\delta_1 + \lambda a^2\, T_1/4h(\lambda + \mu) = 0 \ldots\ldots\ldots\ldots\ldots (25)$$

From (23′) and (25) it follows

$$a_o = T_1[2(\lambda + \mu)h^2 + \lambda a^2]/4h\lambda(\lambda + \mu) \ldots\ldots\ldots\ldots\ldots\ldots (26)$$

Then, on inserting (26) in (23′)

$$\delta_1 = T_1[2(\lambda + \mu)^2h^2 + \lambda\mu a^2]/8h\lambda\mu(\lambda + \mu) \ldots\ldots\ldots\ldots\ldots (27)$$

Finally, from (14)

$$\alpha_1 = [(\lambda + 2\mu)/\mu]a_o - \delta_1 = T_1[\lambda(2\lambda + 3\mu)a^2 + 2(\lambda + \mu)(\lambda + 3\mu)h^2]/8h\lambda\mu(\lambda + \mu) \ldots\ldots (28)$$

Now on substituting (26), (27), and (28) into (20) and transforming, we obtain the following expression

$$w = -[\lambda a^2/8\mu h(\lambda + \mu)]T_1z - [(3\lambda + 2\mu)/24h\mu(\lambda + \mu)]T_1z^3 + [\lambda T_1/8\mu h(\lambda + \mu)]x^2z \ldots (29)$$

and for $z = \pm h$

$$w = \pm T_1(-K_o + K_2x^2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (30)$$

It is clear that $K_2 > 0$ and $K_o > 0$. Thus, for a small value of x, w has the sign of T_1 on the bottom face and the opposite on the upper face. But T_1 is negative, since the traction on the positive side of x has the opposite direction. Therefore in the neighborhood of the face $x = 0$, the strip will be thickened and to that degree of approximation the surface has the form of a parabolic cylinder. Eq. (30) shows that at a distance $x_o = \sqrt{K_o/K_2}$, w vanishes and for $x > x_o$ changes sign, that is, the strip begins to be contracted. It is obvious that (30), holding in the close neighborhood of the plane $x = 0$, cannot represent the whole surface of the deformed strip, which is given by (7) for $z = \pm h$, but the curved faces after making a buckle (or many buckles) must approach the edges $x = \pm a$, $z = \pm h$.

The above solution is of interest, since it shows that the strip being thickened in the region of small values of x forms symmetrical buckles on both faces $z = \pm h$. It is obvious that, if we take into account the boundary conditions, which correspond more to a real case, for example the free upper surface of the strip and the tangential stresses on its bottom face, there will be no symmetry in regards to the coordinate z and the buckling. However, it may be expected that the strip will show a tendency to bend as a whole and to thicken at some places.

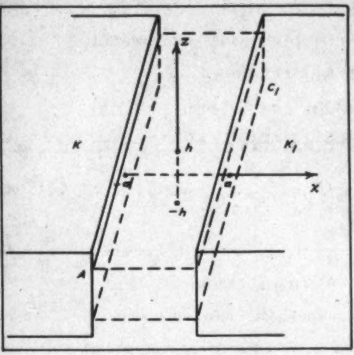

Fig. 3--Formation of an intercontinental mountain range

Intercontinental ranges--We proceed now to the analysis of the third typical case and assume that a strip of matter AC_1 (see Fig. 3), a geosyncline, is compressed by two shields or two continents (K and K_1). Let the cross-section of the strip be a rectangle (2a, 2h). We shall consider again a state of the plane strain. Let Oyz be the plane of symmetry. Then the displacements u and w will satisfy the conditions (10). We assume further that the strip is supported by a substratum. If the strip is narrow and the principal part of its deformation is to be ascribed to the lateral pressure, we may neglect the tangential stresses along its bottom face. Taking isostasy into account, the normal pressure P_o on the bottom face will balance the weight of the strip and on neglecting the variations of the gravity accelerations g, we write

$$p_o = 2hg\rho \quad \ldots\ldots\ (31)$$

where ρ is the constant density of the strip. The displacements u and w must be now solutions of the equations

$$\mu\nabla^2 u + (\lambda + \mu)\partial\theta/\partial x = 0 \ , \quad \mu\nabla^2 w + (\lambda + \mu)\partial\theta/\partial z - \rho g = 0 \ \ldots\ldots\ (32)$$

and are again biharmonic functions.

We will try to satisfy all the conditions of the problem on putting

$$\left.\begin{aligned} u &= u_1 + u_2 = \sum_{n=1}^{\infty} X_n \sin mx + Cx \\ w &= w_1 + w_2 = \sum_{n=1}^{\infty} Z_n \cos mx + \alpha_o + \alpha_1 z + \alpha_2 z^2 \end{aligned}\right\} \ldots\ldots\ (33)$$

since u is an odd function of x, and w an even function, and in which $m = n\pi/2a$. If the products $X_n \sin mx$ and $Z_n \cos mx$ are biharmonic functions, the first factors must have the form

$$X_n = C_n \cosh mz + D_n \sinh mz + z(C_n' \cosh mz + D_n' \sinh mz) \ \ldots\ldots\ (34)$$

$$Z_n = A_n \cosh mz + B_n \sinh mz + z(A_n' \cosh mz + B_n' \sinh mz) \ \ldots\ldots\ (35)$$

The divergence

$$\theta = \partial u/\partial x + \partial w/\partial z = \sum_{n=1}^{\infty} (mX_n + dZ_n/dz) \cos mx + C + \alpha_1 + 2\alpha_2 z \ \ldots\ldots\ (36)$$

must be a solution of the Laplace's equation $\nabla^2\theta = 0$ and this fact implies the conditions for the constant coefficients $A_n, C_n, \ldots.$ in (34) and (35). On substituting the last expressions in the Laplace's equation, we obtain

$$D_n' = -A_n' \ , \quad C_n' = -B_n' \ \ldots\ldots\ (37)$$

Having fixed the boundary conditions for the upper and bottom faces of the strip

$$X_z = Z_z = 0 \ , \quad \text{for } z = +h; \quad X_z = 0 \ , \ Z_z = p_o = \text{const.} \quad \text{for } z = -h \ .\ .\ (38)$$

we proceed to the choice of conditions for the faces x = ±a. We could hypothesize the boundary stresses, as it is usually done in the theory of plates; for example, for x = ±a we could put

$$X_x = P(z) = \Sigma K_n z^n \ , \quad X_z = \overline{X}_z(z) \ \ldots\ldots\ (39)$$

where P and $\overline{X}_z$ are given functions, but it is rather difficult to write some plausible expressions for these functions. On the other hand from geological observations it will perhaps be easier to find the displacements of the edges of a geosyncline. Therefore we assume for x = ±a that

$$u = \mp u_o \ , \quad w = \sum_{n=1}^{\infty} \beta_n z^n + \alpha_1 z + \alpha_2 z^2 \ \ldots\ldots\ldots\ldots \ (40)$$

and obtain mixed boundary conditions. From the first of (40) and (33) it follows that

$$[u]_{x = \pm a} = \sum_{n=1}^{\infty} X_n \sin(\pm n\pi/2) \pm Ca = \mp u_o$$

and since $\sin(\pm n\pi/2) = 0$ for $n = 2K$ we have to put $X_{2K+1} = 0$, that is,

$$C_{2K+1} = D_{2K+1} = C'_{2K+1} = D'_{2K+1} = 0 \ \ldots\ldots\ldots\ldots \ (41)$$

and

$$C = -u_o/a \ \ldots\ldots\ldots\ldots \ (42)$$

Then, from (37) it follows that

$$A'_{2K+1} = B'_{2K+1} = 0 \ \ldots\ldots\ldots\ldots \ (43)$$

On taking into account the conditions of (38): $X_z = 0$ for $z = \pm h$, we have

$$(1/\mu)X_z = \partial u/\partial z + \partial w/\partial x = \Sigma(dX_n/dz - mZ_n)\sin mx = 0$$

On putting the coefficients of sin mx equal to zero, we obtain two sets of relations connecting the coefficients A_n, B_n, ...

$$\left.\begin{aligned} m(D_n - A_n) - B'_n - 2hm \tanh mh \cdot B'_n = 0 \\ m(C_n - B_n) - A'_n - 2hm \coth mh \cdot A'_n = 0 \end{aligned}\right\} \ \ldots\ldots\ldots\ldots \ (44)$$

From these equations and (41) and (43) it follows that

$$A_{2K+1} = B_{2K+1} = 0 \ \ldots\ldots\ldots\ldots \ (45)$$

Thus, the series (33) contains only the terms of the order $n = 2K$. The other boundary conditions of (38) are (see (8) and (33))

$$\lambda\theta + 2\mu\,\partial w/\partial z = \lambda\,\partial u/\partial x + (\lambda + 2\mu)\partial w/\partial z = \begin{matrix} 0 & \text{for } z = +h \\ -p_o & \text{for } z = -h \end{matrix}$$

or

$$\lambda C + (\lambda + 2\mu)(\alpha_1 + 2\alpha_2 z) + \sum_{K=1}^{\infty} [\lambda m X_{2K} + (\lambda + 2\mu)dZ_{2K}/dz] \cos mx = 0 \ , \quad z = +h$$

$$\lambda C + (\lambda + 2\mu)(\alpha_1 + 2\alpha_2 z) + \sum_{K=1}^{\infty} [\lambda m X_{2K} + (\lambda + 2\mu)dZ_{2K}/dz \cos mx = -p_o \ , \quad z = -h$$

We must put the coefficient of cos mx equal to zero, and

$$\left.\begin{aligned} \lambda C + (\lambda + 2\mu)(\alpha_1 + 2\alpha_2 h) = 0 \\ \lambda C + (\lambda + 2\mu)(\alpha_1 - 2\alpha_2 h) = -p_o \end{aligned}\right\} \ \ldots\ldots\ldots\ldots \ (46)$$

These two equations determine the values of α_1 and α_2, since C is given by (42) and p_o by (31). On putting the coefficients of cos mx equal to zero we obtain ($n = 2K$)

$$\begin{aligned} &\lambda m[C_{2K} \cosh mh + D_{2K} \sinh mh - hB'_{2K} \cosh mh - hA'_{2K} \sinh mh] \\ &+ (\lambda + 2\mu)[mA_{2K} \sinh mh + mB_{2K} \cosh mh + mhA'_{2K} \sinh mh + mhB'_{2K} \cosh mh \\ &+ A'_{2K} \cosh mh + B'_{2K} \sinh mh] = 0 \end{aligned}$$

$$\begin{aligned} &\lambda m[C_{2K} \cosh mh - D_{2K} \sinh mh + hB'_{2K} \cosh mh - hA'_{2K} \sinh mh] \\ &+ (\lambda + 2\mu)[-mA_{2K} \sinh mh + mB_{2K} \cosh mh + mhA'_{2K} \sinh mh - mhB'_{2K} \cosh mh \\ &+ A'_{2K} \cosh mh - B'_{2K} \sinh mh] = 0 \end{aligned}$$

On adding and subtracting these equations and dividing by cosh mh and sinh mh respectively, we obtain

$$\left.\begin{aligned}&\lambda mC_{2K} + (\lambda + 2\mu)mB_{2K} + (\lambda + 2\mu + 2\mu mh \tanh mh)A'_{2K} = 0\\&\lambda mD_{2K} + (\lambda + 2\mu)mA_{2K} + (\lambda + 2\mu + 2\mu mh \coth mh)B'_{2K} = 0\end{aligned}\right\}\ldots\ldots\ldots (47)$$

Eq. (44) and (47) contain six unknown quantities A_{2K}, B_{2K}, A'_{2K}, B'_{2K}, C_{2K}, and D_{2K}. But we have made use only of the first of the boundary conditions of (40) for the faces $x = \pm a$. If we expand now the functions of z in the expression Z_{2K} (35), n = 2K, in power series we obtain

$$\begin{aligned}&A_{2K}[1 + (K\pi/a)^2z^2/2! + \ldots.] + B_{2K}[(K\pi/a)z + (K\pi/a)^3z^3/3! + \ldots.]\\&\quad + A'_{2K}[z + z^3(K\pi/a)^2/2! + \ldots] + B'_{2K}[(K\pi/a)z^2 + \ldots.]\ldots\ldots\ldots\ldots (48)\end{aligned}$$

Putting equal the coefficients of equal powers on the left and right side of (40) respectively, we have a set of equations, each of which contains an infinite number of unknown quantities. We write at first these relations, on assuming that the index n in the series (40) has only even values, n = 2K. Then, it follows from (40), (35), and (48)

$$\left.\begin{aligned}&\sum_{K=1}^{\infty} A_{2K}\cos K\pi = -\alpha_0 \;,\; \sum_{K=1}^{\infty}[(K\pi/a)B_{2K} + A'_{2K}]\cos K\pi = 0\\&\sum_{K=1}^{\infty}[(K\pi/a)^2A_{2K}/2! + (K\pi/a)B'_{2K}]\cos K\pi = \beta_2 \;,\; \sum_{K=1}^{\infty}(K\pi/a)^2[(K\pi/a)(B_{2K}/3!\\&\qquad + A'_{2K}/2!)]\cos K\pi = 0\\&\sum_{K=1}^{\infty}(K\pi/a)^3[(K\pi/a)(A_{2K}/4!) + (B'_{2K}/3!)]\cos K\pi = \beta_4\;,\ldots\ldots\end{aligned}\right\}\ldots (49)$$

The conditions (49) contain all the unknown coefficients. Nevertheless, it seems to be possible to obtain an arbitrary approximation, since we have for each K, 6K + 1 unknown quantities A_{2K}, ... D_{2K}, and α_0 and the same number of equations: 2K of (44), 2K of (47), and 2K + 1 of (49). For the first approximation we put K = 1 and

$$\left.\begin{aligned}u &= \Big\{C_2\cosh(\pi z/a) + D_2\sinh(\pi z/a) - z[B'_2\cosh(\pi z/a) + A'_2\sinh(\pi z/a)]\Big\}\sin(\pi x/a)\\&\qquad - (u_0/a)x\\w &= \Big\{A_2\cosh(\pi z/a) + B_2\sinh(\pi z/a) + z[A'_2\cosh(\pi z/a) + B'_2\sinh(\pi z/a)]\Big\}\cos(\pi x/a)\\&\qquad + \alpha_0 + \alpha_1 z + \alpha_2 z^2\end{aligned}\right\}. (33')$$

$$\left.\begin{aligned}&\pi(D_2 - A_2)/a - [1 + (2\pi h/a)\tanh(\pi h/a)]B'_2 = 0\\&\pi(C_2 - B_2)/a - [1 + (2\pi h/a)\coth(\pi h/a)]A'_2 = 0\end{aligned}\right\}\ldots\ldots\ldots\ldots\ldots (44')$$

$$\left.\begin{aligned}&(\lambda\pi/a)C_2 + (\lambda + 2\mu)(\pi/a)B_2 + [\lambda + 2\mu + 2\mu(\pi h/a)\tanh(\pi h/a)]A'_2 = 0\\&(\lambda\pi/a)D_2 + (\lambda + 2\mu)(\pi/a)A_2 + [\lambda + 2\mu + 2\mu(\pi h/a)\coth(\pi h/a)]B'_2 = 0\end{aligned}\right\}\ldots\ldots\ldots (47')$$

$$A_2 = \alpha_0 \;,\quad (\pi/a)B_2 + A'_2 = 0 \;,\quad (\pi^2/2a^2)A_2 + (\pi/a)B'_2 = -\beta_2 \;\ldots\ldots\ldots (49')$$

There are also (46) in the form

$$\begin{aligned}&-\lambda(u_0/a) + (\lambda + 2\mu)(\alpha_1 + 2\alpha_2 h) = 0\\&-\lambda(u_0/a) + (\lambda + 2\mu)(\alpha_1 - 2\alpha_2 h) = -p_0\end{aligned}$$

Hence

$$\alpha_1 = -p_o/2(\lambda + 2\mu) + \lambda u_o/a(\lambda + 2\mu) \quad , \quad \alpha_2 = p_o/4h(\lambda + 2\mu) \quad \ldots\ldots\ldots\ldots \quad (50)$$

α_2 is positive, if $p_o > 0$, the sign of α_1 depends upon the sign of the difference $\lambda(u_o/a) - p_o/2$.

The second of (44'), the first of (47'), and the second of (49') form a separate system, the determinant of which is equal to $-2h(\pi/a)^3[\mu \tanh(\pi h/a) + \lambda \coth(\pi h/a)] \neq 0$. Therefore

$$A_2' = B_2 = C_2 = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (51)$$

The remaining group of equations, the determinant of which is also different from zero, enables us to compute the values of the coefficients $A_2 = \alpha_o$, B_2' and D_2, when the Lamé's constants λ and μ, the dimensions of the strip (h and a) and the constant β_2 are known.

The solution (33') takes now the form

$$\left.\begin{aligned} u &= [D_2 \sinh(\pi z/a) - zB_2' \cosh(\pi z/a)] \sin(\pi z/a) - (u_o/a)x \\ w &= [\alpha_o \cosh(\pi z/a) + zB_2' \sinh(\pi z/a)] \cos(\pi x/a) + \alpha_o + \alpha_1 z + \alpha_2 z^2 \end{aligned}\right\} \ldots . \quad (52)$$

Since the coefficient of $\cos \pi x/a$ has the same value for $z = h$ and $z = -h$, the vertical displacements of particles situated on the upper and bottom faces will be given by the formula

$$w = H \cos(\pi x/a) + H_1 \quad , \quad w = H \cos(\pi x/a) + H_2 \quad \ldots\ldots\ldots\ldots \quad (53)$$

where H, H_1, and H_2 are constants. Thus, this solution represents at first a bending of the strip, its both faces being curved into cylindrical surfaces with sections formed by two congruent cosine lines. At $x = \xi$

$$[w]_{z = h} - [w]_{z = -h} = 2\alpha_1 h = \text{constant} \quad \ldots\ldots\ldots\ldots\ldots \quad (54)$$

This constant will be positive if $\lambda u_o/a > p_o/2$, that is, if the displacements in the direction of the x-axis will be great enough to compensate the thinning due to the bending produced by the pressure at the bottom face. Then the thickness of the strip will be increased by the amount $2\alpha_1 h$ everywhere. These conclusions must be changed, if we make a general hypothesis about the values of w on the boundaries $x = \pm a$, namely,

$$[w]_{x = \pm a} = \sum_{n=u}^{\infty} \beta_n z^n + \alpha_1 z + \alpha_2 z^2$$

Since β_1, β_3, ... are not equal to zero, the coefficients (51) will not vanish. Therefore we must take the coefficients of the $\cos(\pi x/a)$ in the form written in (33'). But this coefficient has different values for $z = \pm h$ and

$$w = H \cos(\pi x/a) + H_1 \quad , \text{ for } z = h, \quad w = H' \cos(\pi x/a) + H_2, \text{ for } z = -h$$

Thus, $H_1 - H_2$ being equal to $2\alpha_1 h$

$$[w]_{z = h} - [w]_{z = -h} = (H - H') \cos(\pi x/a) + 2\alpha_1 h \quad \ldots\ldots\ldots\ldots\ldots \quad (55)$$

This formula shows that the thickness of the strip varies with the coordinate x. It is obvious that new variations of the thickness will appear with each cosine term computed by means of (33), (44), (47), and (49). In the second approximation we should have $[w]_{z = h} - [w]_{z = -h} = L_1 \cos(\pi x/a) + L_2 \cos(2\pi x/a) + 2\alpha_1 h$. The resulting form of the faces is determined by the superposition of periodic terms with decreasing wavelength and will be different for $z = \pm h$. We do not consider all possible cases which may take place when different data are taken into account, and will only make the following remark. The solution of the form (55) shows the tendency of an elasto-plastic strip to be thickened in its middle part, if $H - H' > 0$ and $\alpha_1 > 0$.

Himalaya type--As mentioned above, the fourth typical case of the formation of mountain ranges seems to be the Himalaya. It is schematically represented by Figure 4. If we want to have the simplest form of the problem, which can be treated by means of the theory of elasticity, we shall assume that a plate AEOF is dragged by a current against a continent or shield FDCBE in the direction of the diagonal AO. The second plate FDCBE is retained in its position by tangential tractions produced by the substratum in the opposite direction. To make the problem more symmetrical we could imagine a square plate having a side AD = 2AF cut out of the continent, but we

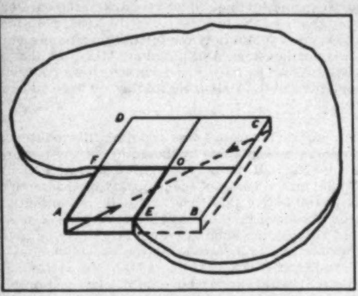

Fig. 4--The case of the Himalaya

do not give here the mathematical solution of this problem. It is easy to see that a pressure acting along the sides FO and OE, while the two other sides AF and AE are free, can produce a broken mountain range FOE.

If the form of mountain ranges at the present time differs from one of the four typical forms enumerated above, there are two reasons for the deviation. The initial conditions were undoubtedly very various in different parts of the Earth's crust and the geosynclines were in general bounded by some curved faces. But the initial form of a mountain range, regular or irregular, could be changed during the latter geological periods by the deformation of the moving continents. Among many such cases the most evident are perhaps the Alaska range and the Cordilleras at the south end of South America. It is very important for the study of the dynamics of the Earth's crust to establish for all mountain ranges, whether their curved form is due to the initial form of the geosynclines or to a later deformation.

The field of forces acting in the crust--It is well known that the mountain ranges were not scattered at random on the Earth's surface. We possess now positive data concerning the Tertiary belt, less positive perhaps concerning the variscides and caledonides, and fragmentary data about the older diastrophism (see, for example, the map given by UMBGROVE [1942]). This distribution of mountain ranges (the positions as well as the succession in time) is the most important fact, which must be explained by the theory of orogeny. It is insufficient to point out some probable causes which could produce the folding in general or to find some configurations which would correspond to an isolated effect, as is done in some recent theories. To solve the problem of the orogeny means, as mentioned above, to show the field of forces and the phenomenon creating this field, which is able to produce the folding just in the regions where and during the geological period when it occurred.

Not rejecting completely the possible effects of shrinkage caused by the cooling of the Earth, of the irregular convective currents and of the gliding of the whole crust on the core, the writer suggested [JARDETZKY, 1935] the principal role which could be played by the zonal rotation of the Earth. This phenomenon, observed at the present time on the Sun, Jupiter, and Saturn, consists in a torsion of the whole Earth's body (a torsion of another kind was suggested by Prinz, Daubrée, and others).

On assuming the zonal rotation corresponding to an equatorial acceleration, for example, such as follows from the law of Carrington-Faye, we may deduce the field of forces due to a shear in different zones and pressure on the floating bodies on the Earth's surfaces. But the idea of the zonal rotation is not connected with the liquid state of the whole Earth. After the rigid crust was formed, this kind of internal movement could remain in the fluid core as well as in the regions with properties of a plastic material and produce the corresponding stresses in the solidified upper layers of the Earth. Combined with the postulated existence of one continental block, the hypothesis of the zonal rotation of the Earth can explain the form of existing continents (as was shown theoretically and experimentally). On the other hand this hypothesis shows in what regions the formation of the mountain ranges is to be expected. This distribution agrees with the Tertiary belt and we shall mention the principal conclusions derived from the schematical representation of the process. (1) Before and after the rupture of the continental block the mountain ranges should be formed along the western coast of America, the north-eastern border of Asia, the eastern border of Australia, New Zealand and the Antarctic. (2) After the rupture of the continental block, when the separated continents began to rotate about vertical axes, the mountain-building was probable: in the region where Africa and Europe were pressed one against the other (Alps, Atlas, ...), along the northwestern coast of North America and southwestern coast of South America which were pressed against the bottom of the Pacific. (3) The Indian shield could be pushed into the principal part of Asia, on forming the Tertiary folding of the Himalaya. (4) The other mountain ranges of the intercontinental type would be possible on weaker places of the Earth's surface.

Thus the regions determined by the hypothesis of the zonal rotation as most favorable to the folding coincide with the areas of the Cenozoic and Mesozoic folding. If we go back to the earlier geological periods, we see that the field of forces as given by the hypothesis of the zonal rotation and nearly the same positions of the poles of rotation, can explain only the formation of some variscides and caledonides (those in eastern Australia and northeastern Asia, Kunlun, Atlas, but the formation of the Appalachian and Scandinavian mountains can be hardly understood, if we postulate only this field of forces). Thus, to obtain the true picture of the Paleozoic folding we have to complete our scheme by the action of some other factors.

The changes of the field of forces--The periodic character of the diastrophism, the existence of many phases during the same geological period cannot be explained by the action of any factor mentioned above. The forces taken into account act through all the periods. An explanation of the periodicity in orogeny was suggested by GRIGGS [1939] on the basis of the property of spasmodic flow of the materials forming the crust. It is quite possible that this flow, or the displacements in the solid layers, occurs when the tangential stresses produced by the substratum surpasses some definite limit. Then, after a certain time interval of release the subcrustal currents may be able to produce the same effect again. It seems to the writer that this representation should be combined with the following fact. During his experiments [JARDETZKY, 1948a, 1948b] the writer has often observed that a viscous substratum, a heated pitch, could flow under a solid plate and only drag it, but after being cooled it became more viscous and produced the rupture of the plate.

It is obvious that the folding of the solidified upper layer of the Earth's crust could have happened when the tangential stresses along its bottom face surpassed some limit. As to this limit, there is, besides the properties of the material another factor influencing its value, namely the thickness of the layer, and it depends on the viscosity of the substratum too, whether this limit will be surpassed or not. Thus, after the formation of a thin solid crust the cooling of the Earth should provoke at first the increasing viscosity of the substratum and when the increasing tangential stresses reached a certain value T_1 they could fold a shell having a thickness d_1. The new distribution of masses could resist the relaxed stresses, and there was a time interval, during which the thickness was grown, and the stresses T_1 could not produce the folding. For the new thickness $d_2 > d_1$ a greater viscosity and tangential stresses were necessary in order to deform the shell. With the continued cooling there were increasing thicknesses $(d_1 < d_2 < \ldots . d_n < \ldots .)$ and the increasing viscosity and tangential stresses $(T_1 < T_2 < \ldots . \quad T_n < \ldots .)$. The process of folding should be finished when the crust becomes so thick as to make impossible any deformation of the the outer shell by the displacements of the substratum.

Thus, both factors, the above property of materials and the cooling which produced the thickening of the Earth's crust and the increase of the viscosity, acting simultaneously in the same sense could produce the phases in mountain building.

But there could be other changes of the field of forces occurring through several geological periods. In the further investigations of the problem of the mountain building there should be taken into account the probable deviations from the pure zonal rotation represented by the law $w = a - b \sin^2 \phi$ (where w is the angular velocity, ϕ the geographical latitude and a and b two positive constants); and the large displacements of the poles which undoubtedly have produced a shear, whose patterns are taken as a basis of the recent theory of VENING MEINESZ [1947].

It follows from the quoted map of Umbgrove that at the present time we can hardly find some general laws concerning the distribution of the Pre-Cambrian folding. More detailed data are required in order to make possible some plausible conclusions. The first period of folding over large areas of all continents was the most complicated one and it is very probable that this folding, as mentioned above, was the result of action of all enumerated factors.

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PRESSURE SHADOWS AND RELATIVE MOVEMENTS IN A SHEAR ZONE

H. W. Fairbairn

Abstract--The determination of direction-sense of movement by means of pressure shadow orientation has been investigated by MÜGGE [1930] in some detail. As far as the writer knows, no correlation of this deduced direction-sense with a field example of relative movement has previously been made. Study of an oriented specimen taken from the Campbell shear zone at Yellowknife (N. W. T., Canada), where the direction-sense of movement has been established with reasonable certainty, now provides this correlation. Interpretation of the pressure shadow orientation around pyrite grains in the rock confirms the field data in every way. It would seem that this structure warrants closer attention and application than it has received heretofore.

Introduction--In the study of faults and shear zones it is essential to determine both direction and direction-sense of movement. In some cases the former may be known, with uncertainty about the latter. Most geologists prefer field evidence to petrofabric evidence in determining the character of the movement and with this point of view there can be no fundamental quarrel. However, if field evidence is uncertain, or absent, as in the relatively wide shear zones of some metamorphic terranes, it is imperative to use all available petrofabric criteria as a guide. Of these, the spiral arrangement of inclusions in "snowball" garnet is perhaps best known. This paper is concerned with another criterion, less well known, but equally powerful in its application to problems involving relative movement, that is, pressure shadows surrounding porphyroblasts. The best analysis of pressure shadows known to the writer is that of MÜGGE [1930] and a transcript of some of his work can be found in "Structural petrology of deformed rocks [FAIRBAIRN, 1949; Chap. 3 and 12]. PABST [1931] has also contributed to the subject. (Reference to previous work by Knopf, Moss, and Fischer can be found in this paper.) No attempt is made to recapitulate this work here and the reader unfamiliar with pressure shadows should refer to these sources.

Pressure shadows from the Campbell shear zone--An oriented specimen of pyritiferous schist collected by the writer from the Campbell shear zone, Con Mine, Yellowknife, N. W. T.,

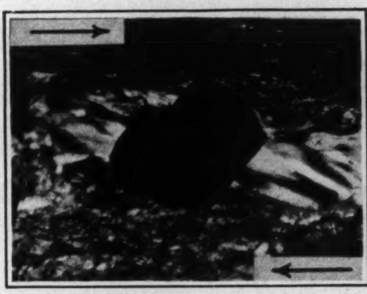

Fig. 1--Photomicrograph showing feather quartz in pressure shadow formed by pyrite, Campbell shear zone (2300 ft level), Con Mine, Yellowknife, N. W. T., Canada; arrows indicate character of relative movement necessary to explain the development of the feather quartz; foliation runs EW, polarized light, X 70

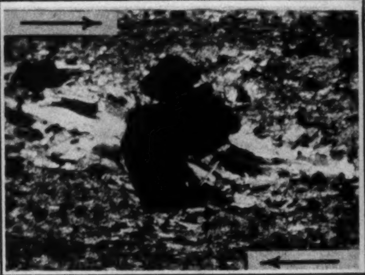

Fig. 2--From same specimen and locality as Figure 1; feather quartz trend lines have slight curvature, becoming parallel with foliation at the ends; foliation runs EW, polarized light, X 23

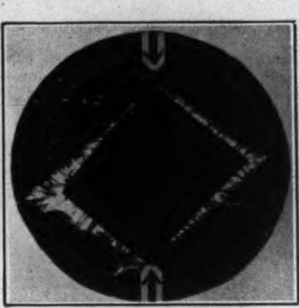

Fig. 3--Photomicrograph of pyrite porphyroblast in graphitic slate showing pressure shadow of feather quartz, near Carson Hill, Mother Lode, California; foliation trend is EW; after PABST [1931]; polarized light, X 8

Canada, is the source of the pressure shadows under consideration here [CAMPBELL, 1947]. A number of thin sections were cut parallel to the lineation and normal to the foliation. Since the main glide plane in the shear zone is assumed to be parallel to foliation and the main glide line parallel to lineation, the thin sections are therefore parallel to the deformation plane in the rock. Many of the small pyrite grains seen in these oriented sections have tails of feather quartz in pressure shadow pockets on opposite ends of the grains. These areas are arranged asymmetrically with respect to the foliation trend and show a consistent orientation (see Fig. 1 and 2). This orientation in turn indicates a direction-sense of movement as shown. It turns out that this deduced relative movement has the same sense as that determined from geological evidence in the mine, so that for the first time, so far as the writer is aware, field and fabric evidence can be correlated with respect to this important structural criterion. The evidence from one specimen does not necessarily establish the relation for the entire shear zone; nevertheless, it is probable that study of additional specimens would lead to the same conclusion.

Magnitude of movement--Pressure shadows do not give any significant data on amount of movement. This is obvious from their character as appendages to the host crystal. The shadow mineral, in this example quartz, can only grow in the protected sides of the host. As the host rotates, carrying the quartz feathers with it, the latter will be gradually removed from the protected shadow zone and be granulated and incorporated into the schist. There is an indication of this in Figure 2, where the lower side of the right-hand quartz area is truncated parallel to the east-west plane of movement. In contrast, Figure 1 indicates a stage of growth with temporary absence of movement. As deformation continues new quartz feathers will develop on pyrite surfaces rotated out of the exposed zone, so that the general appearance of the shadow area will not be changed. This contrasts with pressure shadows of the type shown in Figure 3 [PABST, 1931] where the symmetry of the structure precludes couple action parallel to the EW foliation. Here the prolongation of the feather quartz areas at the ends of the host pyrite has a relation, more or less direct, to the actual shortening and elongation of the schist fabric.

Lattice orientation--A survey of the quartz grains in these pressure shadow pockets fails to show any significant preferred orientation. This confirms previous work [PABST, 1931] and further establishes them as growth fabrics, entirely free of deformation influences. It was not practical by optical methods to determine the quartz orientation in the schist, but a typical girdle orientation of some kind may safely be predicted. Information on lattice orientation is in general unnecessary for pressure shadow analysis, which will be good news for those not equipped for, or not interested in, this aspect of deformation study.

Conclusion--The preceding brief note shows a nice correlation of field and petrofabric data. It indicates that pressure shadows, theretofore looked upon mostly as microtectonic show-pieces, may have considerable significance for the field geologist, especially if ordinary field evidence fails to establish the direction-sense of movement. A necessary condition of course is that porphyroblasts of some kind be available to act as hosts for the shadow minerals. It is probable that these structures are more abundant than at present suspected and every effort should, therefore, be made to locate and use them.

Acknowledgment--The writer is indebted to Neil Campbell, District Geologist, Consolidated Mining and Smelting Company, Yellowknife, for courtesies extended during a visit to the Con Mine in August, 1949.

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GRAVITY MEASUREMENTS AT SEA, 1947

J. Lamar Worzel and Maurice Ewing

(Contribution No. 543 from the Woods Hole Oceanographic Institution)

Abstract--A long-range program of gravity measurements at sea has been instituted. The measurements are made on board United States submarines. The Vening Meinesz pendulum apparatus is being used with improved timing provided by a crystal chronometer, and timing marks inserted by spoked wheels of a synchronous motor. Data to make second-order correction terms of Browne are observed with the Vening Meinesz long-period pendulum apparatus. A precise depth gage record is made and correlated with the pendulum record. During 1947 gravity observations were made as follows: 104 on U.S.S. Tusk along the east coast of the United States north of Cape Hatteras, 86 on U.S.S. Conger along the west coast of South America, and 56 on U.S.S. Conger along the north coast of South America.

Introduction--A program of gravity measurements at sea was begun aboard United States Navy submarines in 1947 by graduate students of the Geophysical Laboratory, Department of Geology, Columbia University, under the direction of Maurice Ewing. This work was begun under the joint auspices of the Geological Society of America and the Office of Naval Research, Navy Department.

The arrangements for the cruises were made with the assistance of Commander, Submarine Force, United States Atlantic Fleet, and the Chief of Naval Operations. The officers and men of U.S.S. Tusk and U.S.S. Conger have all cooperated to make the work a success. The cooperation from the Submarine Force was indispensible since the measurements can only be made on a submerged submarine.

The gravity pendulum apparatus was developed by Vening Meinesz in an epoch-making contribution to the science of geodesy. This apparatus was described by VENING MEINESZ [1929]. The actual equipment was that used [EWING, 1937] on U.S.S. Barracuda in 1936-1937.

Instrumentation--Some improvements in the timing system have been effected by the use of the Bell Laboratories crystal chronometer [MARRISON, 1948]. A synchronous motor is operated by the crystal oscillator. By suitable gearing, a disk with ten spokes is driven at two revolutions per second. This disk is placed so that it interrupts the light beam prior to its introduction to the various pendulums (see Fig. 1). This disk therefore interrupts the light beam each 1/20 sec. In addition, a second wheel rotating at one revolution per second has spokes which interrupt the light beam between the interruptions of the first disk on each alternate rotation of the first disk. This latter disk makes the phase relations of the various pendulums visible. A contactor also operated by the synchronous motor and utilizing one of the original relays provided for time interruption interrupts the light beam for about two seconds each minute. This permits the elapsed time or the number of swings to be rapidly determined at any place along the record without having to count all the pendulum oscillations.

On top of the synchronous motor a strobotron lamp is mounted. When time comparisons are desired, this tube is made to flash from the radio time signals of WWV. The numbers on the wheel visible in the slot beneath the lamp represent tenths of seconds and the vernier near the outer edge of the wheel makes it possible to obtain a time comparison to 1/1000 sec. A rate curve for a 20-day period is shown in Figure 2. The fluctuations in rate are principally caused by temperature changes within the submarine since the crystal is not temperature controlled. Curves A and B s show the slopes of the rate curve which would cause a gravity correction of 1/2 milligal.

Vening Meinesz generously loaned a long-period pendulum apparatus which he had developed to measure the second-order corrections [VENING MEINESZ, 1941a] for horizontal and vertical acceleration. The need for these corrections had been pointed out by BROWNE [1937]. This apparatus (see Fig. 3) consists of two long-period pendulums (approximately 26 sec) oriented to measure the two components of horizontal acceleration. Since water-wave periods are seldom greater than ten or 15 sec, these pendulums essentially maintain their position in the gravitational field

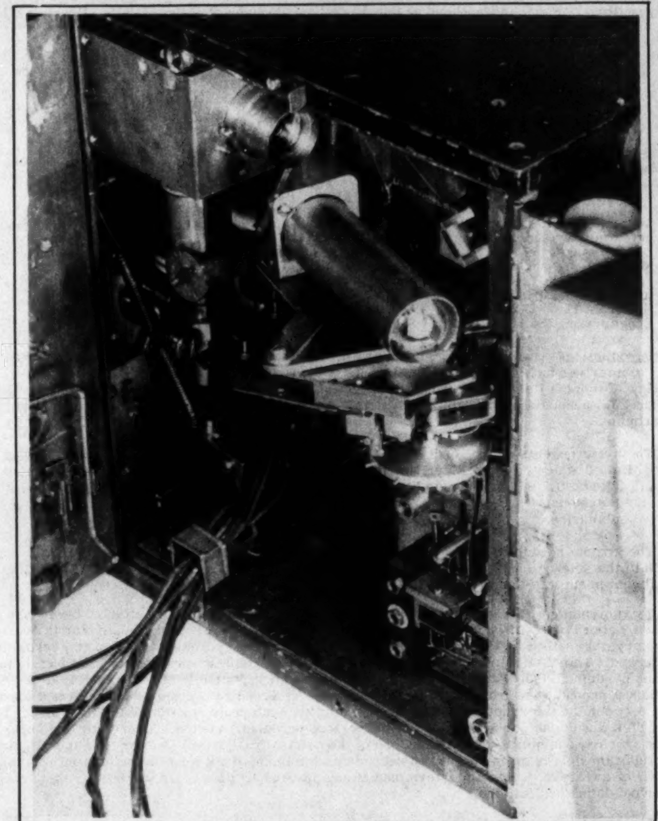

Fig. 1--Synchronous motor and light interrupter disks

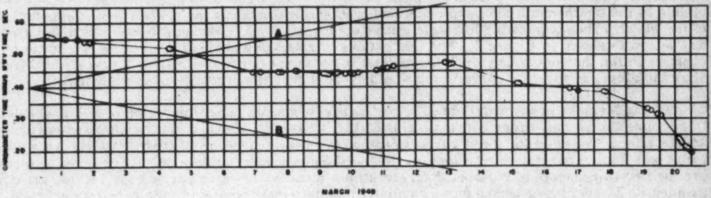

Fig. 2--Crystal chronometer rate, U.S.S. Argonaut

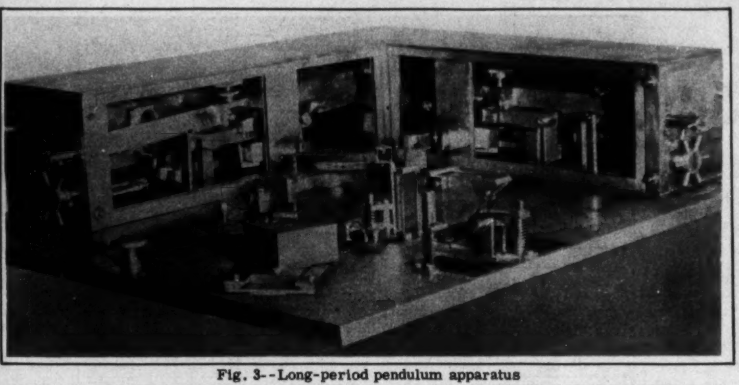

Fig. 3--Long-period pendulum apparatus

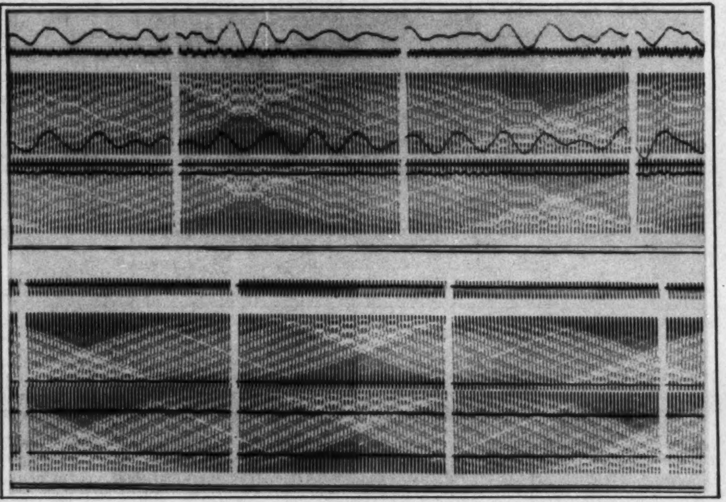

Fig. 4--Gravity records in rough conditions (top) and smooth conditions (bottom)

and are relatively unaffected by the horizontal accelerations caused by the waves. Air damping of the pendulums is provided as well as suitable lifting and calibrating devices. The optical system is so arranged that the deflection of these pendulums relative to the main pendulum case can be determined. The traces of their motions are superimposed on the record of the main pendulum apparatus. The long-period pendulum apparatus is placed between the main pendulum case and the recording camera.

Figure 4 shows parts of two gravity records. The upper record was obtained on a dive in a fairly rough sea, while the lower one was obtained on a calm day in the protected waters of the

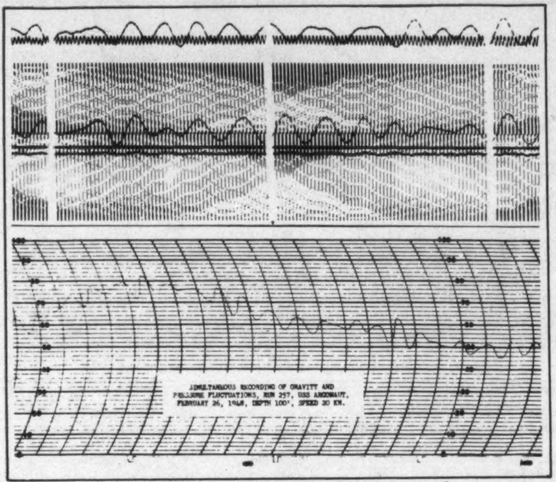

Fig. 5--Simultaneous gravity and Mark I record

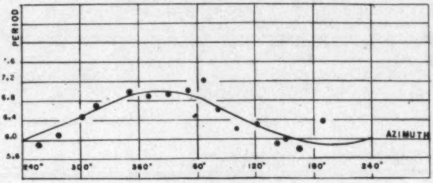

Fig. 6--Doppler effect on surface wave periods

Tongue of the Ocean, in the Bahamas. In each record the top trace is the long-period pendulum transverse to the main axis of the vessel, while trace four is the long-period pendulum parallel to this axis. The second trace is the middle pendulum of the main apparatus while the third and seventh traces are the fictitious pendulums made by optically combining the middle pendulum with each outside pendulum. The fifth trace is the record of the thermal element and the sixth is the record of the damped pendulum in the plane perpendicular to the plane of the main pendulums. The narrow interruptions easily seen on the fictitious pendulum traces are those caused by the 1/20-sec interrupter. The phase relations are quite obvious from the wider interruptions on these same traces. Note the disturbance of the eclipse lines caused by the vertical accelerations. The ten separate spokes of the main eclipse wheel effectively allow the period of the pendulums to be determined by ten separate accurate clocks. Since each spoke interrupts the light beam twice a second, at any place in the record one upward sloping line of interruptions and one downward sloping line are made by the same spoke. The intersection of these two lines marks the center of the pendulum record more accurately than it is possible to measure from the edges of the traces.

In addition to the gravity apparatus, a Naval Ordnance Laboratory Mark I low-frequency hydrophone is used as a precise depth gage. A record from this instrument is shown alongside a gravity record taken at the same time in Figure 5. The time marks along the top of the Mark I record are controlled by the same minute contactor that controls the minute marks on the gravity records, so

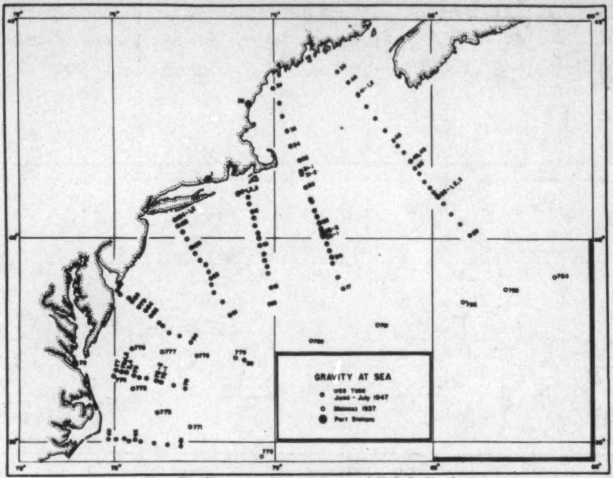
GRAVITY AT SEA
USS Tusk June - July 1947
Meinesz 1937
Port Stations

Fig. 7--Gravity observations of U.S.S. Tusk

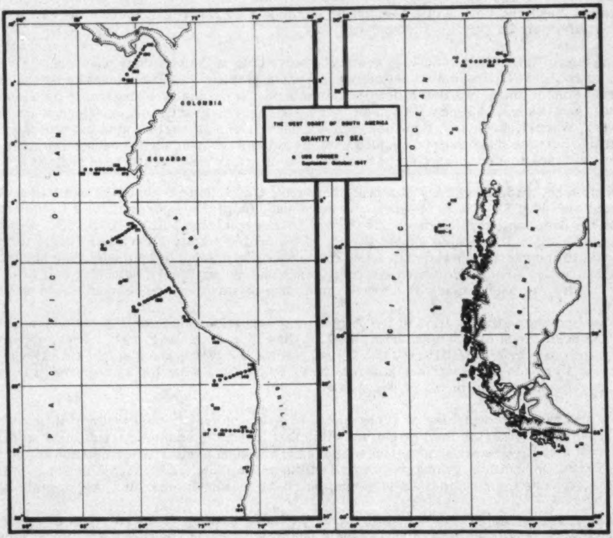
THE WEST COAST OF SOUTH AMERICA
GRAVITY AT SEA
USS Conger September October 1947
COLOMBIA
ECUADOR

Fig. 8--Gravity observations of U.S.S. Conger I Cruise

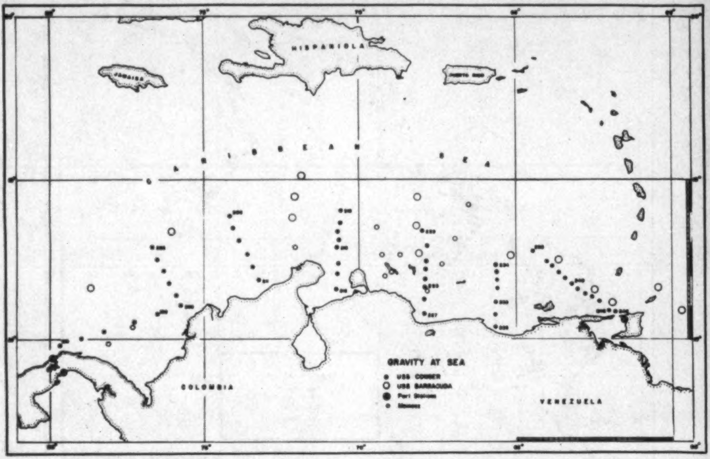

Fig. 9--Gravity observations of U.S.S. Conger II Cruise

that the two records may be directly correlated. Some observations have been made on circular courses to check the Eötvös effect on gravity. The Mark I records of these observations show the Doppler effect on the surface wave periods (see Fig. 6).

Cruises--U.S.S. Tusk made 104 gravity observations at the positions shown in Figure 7 in June and July, 1947. Previous observations by Vening Meinesz in 1937 are shown by the smaller circles. Four of these profiles follow the seismic profiles made by this group in previous years [EWING and Others, 1937; EWING and Others, 1950]. The gravity observations were made by Ewing, Worzel, Steenland, Hamilton, and Wuenschel, who all participated in various parts of this cruise. These observations coupled with the seismic evidence will provide a much better idea of the transition from continent to ocean basin than has ever before been available.

Wuenschel made 86 gravity observations aboard U.S.S. Conger along the west coast of South America (see Fig. 8). These observations were made on profiles perpendicular to the coast and across the deep topographic trench and the earthquake epicenter belt [GUTENBERG and RICHTER, 1941] which follow this coast. On the portion of the cruise around Tierra Del Fuego, time commitments of the vessel allowed only a few scattered observations to be made. The observations on these profiles will decide whether a deep trench and an earthquake epicenter belt near a continental border are associated with a gravity minimum belt as they are near an island arc.

Figure 9 shows the location of the 56 gravity observations made on U.S.S. Conger, II cruise, along the north coast of South America, by G. R. Hamilton in October, 1947. Previous observation points made by EWING [1937] and VENING MEINESZ [1941b] are also shown. These observations will provide further information on the location of the West Indian negative gravity trough and about the margins of the Carribbean Sea.

This work is the beginning of a long-range program of gravity observations at sea. The ultimate goal of this program is to cooperate with other groups in obtaining a sufficient worldwide network of gravity observations to make it possible to make a better determination of the figure of the Earth. In addition, geological studies will be made from the gravity data obtained in selected areas, such as the circum-Pacific earthquake belt, continental margins, and oceanic islands.

Acknowledgments--F. A. Vening Meinesz, the Naval Ordnance Laboratory of the Bureau of Ordnance, and the Woods Hole Oceanographic Institution all lent apparatus, thereby making it possible to commence actual measurements of gravity at an early date.

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MAGNETIC WORK OF THE UNITED STATES COAST AND GEODETIC SURVEY FROM JULY 1, 1947 TO JUNE 30, 1949

Elliott B. Roberts

The vital role of geomagnetism in the commerce and affairs of men is a familiar story to readers of these Transactions and need not be stressed here. Observations made in this field are basic to several vital functions of modern life. An effective program to meet these and related needs calls for long-range coordination of work over a vast area, and hence for the direction and participation of a technically qualified staff devoted specifically to this activity. For the United States and its dependencies, this responsibility is included among those historically assigned to the United States Coast and Geodetic Survey in connection with its basic task of providing the navigator and airman with the charted data essential for navigation. The magnetic work and associated research activities are explicitly recognized in the organic act describing the Survey's functions [see 80 U. S. Code 373, Sec. 3].

This report is one of a series, of which the antecedent appeared two years ago [ROBERTS, 1948a]. During the subsequent interval, geomagnetic observing programs have attained new levels of interest and significance as a result of postwar technical and commercial developments in aviation, in exploration geophysics, and in radio techniques. Since the War, there has been an increasing stress on airborne magnetic surveys, which give promise of meeting some of the pressing needs of air navigation in the polar regions and also of relieving the alarming obsolescence of magnetic chart data in the great ocean areas. Such measures will further enhance the value and necessity of continued precise observing programs on the ground, needed both to control and correct the airborne work and to provide essential data not otherwise obtainable.

Magnetic surveys

United States and Alaska--During the period of this report, the store of "repeat" data needed for following the progress of secular change has been steadily built up through the work of three regular field parties, with itineraries traversing most regions of the United States east of the Rocky Mountains. At the same time, other field parties in the United States and Alaska supplied data on the declination. Repeat stations are now being established in close pairs to minimize losses.

Western hemisphere--A Canadian observer was provided with instruments with which he obtained magnetic data during 1947 and 1948 in the region of Lancaster Sound. Magnetic observations made during the period are shown in Table 1. Arrangements were completed by which technical direction and reduction of results will be performed for magnetic surveys to be carried out in Central and South America by the Inter-American Geodetic Survey.

The Coast and Geodetic Survey has cooperated with the Pan-American Institute of Geography and History in setting up standards of American hemisphere magnetic survey practice [ANONYMOUS, 1948b].

Airborne magnetic surveys--Important steps have been taken regarding airborne magnetic surveys. A satisfactory technique for observation of all magnetic components in flight is available. These developments will permit very rapid survey coverage over ocean and polar areas.

Cartographic program

Central depository for magnetic data--Under law, the Coast and Geodetic Survey is the official depository of world-wide magnetic data from all sources. The library of such data has undergone vigorous expansion [ANONYMOUS, 1948a]. The largest single accession was an extensive file of data and reductions pertaining to the series of isomagnetic charts for epoch 1945, deposited by the U. S. Hydrographic Office.

Isogonic charts for 1950--A substantial accomplishment in magnetic chart work is the forthcoming world isogonic chart for epoch 1950.0, compiled by the Coast and Geodetic Survey for

Table 1--Distribution of magnetic observations from July 1, 1947 to June 30, 1949
(The figures preceding and following the semicolons refer to the intervals before and after June 30, 1948, respectively.)

Locality	Repeat stations				Other stations	Total
	New		Old			
	Complete[a]	D only	Complete[a]	D only		
Arkansas	0; 2	..		..	...	2
California	0; 1	..	0; 1	..	...	2
Florida	2; 0	..	3; 1	..	...	6
Idaho	...	..	...	..	6; 6	12
Illinois	1; 0	..	1; 2	..	...	4
Indiana	...	0; 1	...	..	0; 1	2
Kansas	0; 2	..	...	0; 1	0; 2	5
Kentucky	0; 1	..	0; 2	..	...	3
Louisiana	...	..	0; 1	..	...	1
Maine	1; 0	..	1; 0	..	2; 0	4
Maryland	...	..	1; 0	..	...	1
Massachusetts	...	..	...	..	0; 1	1
Michigan	2; 1	..	0; 1	..	0; 2	6
Mississippi	0; 1	..	0; 3	..	...	4
Missouri	0; 1	..	0; 1	..	...	2
Montana	2; 0	..	2; 0	..	...	4
Nevada	1; 1	..	1; 1	..	...	4
New Jersey	1; 0	..	...	..	...	1
North Carolina	...	..	2; 0	1; 0	...	3
North Dakota	1; 0	..	1; 0	..	...	2
Oklahoma	0; 1	..	0; 1	..	...	2
Oregon	...	..	...	..	5; 0	5
Pennsylvania	...	0; 1	0; 1	..	...	2
South Carolina	...	..	1; 0	1; 0	...	2
South Dakota	1; 0	..	1; 0	..	...	2
Tennessee	1; 0	..	1; 0	0; 2	1; 0	5
Texas	0; 1	..	0; 4	..	...	5
Utah	1; 0	..	1; 0	..	...	2
Vermont	2; 0	..	...	..	1; 1	4
Virginia	...	..	...	..	3; 2	5
Washington	...	..	...	..	5; 1	6
Wyoming	1; 0	..	1; 0	..	...	2
Alaska	...	..	...	..	39; 57	96
Total	17; 12	0; 2	17; 19	2; 3	62; 73	207

[a] A complete station comprises measurement of declination, horizontal intensity, and dip, thus completely defining the field.

publication by the Hydrographic Office. This has been effected under a modern agreement for centralization of all technical work in geomagnetic charting in the Survey, utilizing its staff of experienced scientists and magnetic cartographers.

The 1950 isogonic charts of the world and of the United States are compiled together in a joint operation. The use of punch-card methods is an important technical advance in processing the world magnetic data prior to its use by the magnetic cartographers. A large number of cards have been key-punched to show the magnetic data from field stations and observatories in all parts of the world in a uniform arrangement. The data regarding secular change are first processed to yield values for constructing a set of smoothed isoporic charts, each of which depicts the adopted distribution of secular change between successive key epochs, chosen to conform with changes in the rate of secular change registered at magnetic observatories. The secular change is next used in a machine reduction of the main body of data to the desired epoch. Hundreds of thousands of operations are involved. The punch-card machines are extremely rapid and economical in operations of this kind.

The final isogonic charts will appear in 1950 and will include isoporic lines, indicating the present pattern of secular change throughout the world. Correction to actual date of use is thus possible, although required only in the most exacting uses.

The world chart will consist of one Mercator and two polar sheets. The chart for the United States will be on a conformal projection. The data from these charts will be the basis of the isogonic lines and compass roses found in one form or another on all nautical and aeronautical charts.

Other cartographic work--Steps have been taken to effect centralization of magnetic work of the Government in the Survey. International understanding has been reached on standardized epoch dates for magnetic charts of the world as produced by the chief maritime nations, and discussions are looking to international consultation and collaboration.

Charts completed during the report period include the 1945 series of charts for the United States (dip, horizontal intensity, vertical intensity, and secular change) and an isogonic chart of Texas, all printed by the Survey for insertion in publications [DEEL and HOWE, 1948; EATON, 1949], as well as the 1947 edition of the isogonic chart of the Caribbean Sea, Chart No. 2117. Manuscript was prepared for an isogonic chart of northern Venezuela.

Current revisions of compass data were accomplished for several hundred nautical and aeronautical charts issued or revised. Several thousand estimated values of magnetic declination were supplied to the Army Map Service for use on maps published by that Service.

Observatory program

The function of magnetic observatories is to record continuous data on the Earth's magnetic field components, needed in the study and application of the complex secular and short-period changes of the field. One of the uses is in the correction of station values affected by the fluctuations, to prepare them for use in chart construction.

There are seven magnetic observatories of the Coast and Geodetic Survey: Cheltenham, Maryland; Honolulu, T. H.; San Juan, P. R.; Tucson, Arizona; and Sitka, College (near Fairbanks), and Barrow, Alaska. The three Alaskan observatories furnish information in the vicinity of the north polar auroral zone, where ionospheric phenomena and radio-wave propagation constitute related problems of particular importance.

Cheltenham, Maryland--Routine operation of three magnetographs continued. The scale values of the variometers are approximately as shown below. The Adie instruments are equipped with eye-reading scales.

Type	D 1/mm	H γ/mm	Z γ/mm
Eschenhagen	1	2.7	4
Adie	1.1	4	12
La Cour	4	30	. .

Field instruments of the Coast and Geodetic Survey and of other agencies were standardized at Cheltenham. The Department of Terrestrial Magnetism of the Carnegie Institution of Washington cooperated in maintaining the international magnetic standards. The standards of horizontal intensity at Cheltenham and Rude Skov were indirectly compared by means of three Danish QHM's.

Honolulu, Territory of Hawaii--Routine operation of the magnetograph continued throughout the report period.

San Juan, Puerto Rico--Routine operation of the magnetograph continued throughout the report period. The earth inductor was replaced with a new one. The magnetometer was indirectly compared with the Cheltenham standard.

Tucson, Arizona--Normal operation of the magnetic observatory was continued, including cooperative work with the Department of Terrestrial Magnetism, Carnegie Institution of Washington, on atmospheric potential gradient and positive and negative air conductivity. The absolute magnetic instruments were indirectly compared with the Cheltenham standards.

Sitka, Alaska--Two magnetographs (sensitive and insensitive) were maintained.

College, Alaska--With the completion of permanent buildings and installation of equipment, operations at College were placed on a permanent basis in February 1948, replacing a temporary station maintained jointly by the University of Alaska and the Carnegie Institution of Washington until July 1946, and thereafter by the University and the Coast and Geodetic Survey.

Barrow, Alaska--The observatory here, established jointly by the Coast and Geodetic Survey and the Office of Naval Research, USN, commenced operations on May 31, 1949. The Barrow recorder will operate over extended periods without attention when weather conditions interfere with attendance. This observatory will supplement the work of two International Polar Year campaigns of 1882-1883 and 1932-1933, and that of Rochfort Maguire carried out in 1852-1854 in conjunction with the Franklin Search expeditions.

Unattended stations--An automatic declination recording station was continued in operation at Gatlinburg, Tennessee. In October 1947, with the cooperation of the Utah State Agricultural College, a similar station was placed in operation at Logan, Utah.

General phases of observatory program--The abridged scaling program, limited to the last hour of each day, disclosed that investigators valued the older and more comprehensive data more highly than the prompt availability afforded by the abridged scalings. Since March 1948, all hourly mean values of the ordinates have been scaled, and the period of abridged scalings will be filled in.

The great labor of processing the hourly values has always prevented prompt publication of results. Various economies, including direct scaling, have partially relieved the cost of this work, which entailed reading and tabulating thousands of numerical values at several stages of the work, with repeated checks for error. IBM processing will reduce this to but one card punch operation for each hourly value. The cards can be machine-processed through the computation, producing finally a machine tabulation suitable for offset printing.

Instrumental program

Active progress has been made in techniques for the refined measurements required in magnetic work. Development work included a saturable-core magnetometer capable of acceptable results with only about one-tenth as much observing time as conventional instruments. A remote visible magnetograph recorder has reached a final development stage.

Through close cooperation with domestic manufacturers, there have been acquired a number of of new field and observatory instruments of excellent quality, replacing foreign sources of supply. These include standard magnetograph recorders, eight-inch photographic tape recorders, earth inductors, and variometers for declination and for horizontal and vertical intensity. Magnetographs of American manufacture have been inspected and tested, for the National University of Argentina and for the Philippine Republic and the Government of Venezuela. The Bureau has cooperated with Federal and State agencies and with foreign governments in furnishing specifications and other detailed information on geomagnetic instruments, and has lent instruments to expeditions and to the Defense Agencies.

Dissemination of data of magnetic activity

Magnetic conditions, as recorded at the Cheltenham observatory, were reported daily to the Central Radio Propagation Laboratory of the National Bureau of Standards. Regular and special reports were rendered to other Government and research institutions, and to commercial firms. The weekly K-index report of magnetic conditions at Cheltenham was continued. The Bureau and other agencies collaborated with the International Association of Terrestrial Magnetism and Electricity in the compilation of tabulations showing world-wide magnetic activity for the period 1940-1948, partly by means of punched cards [JOHNSTON, SCOTT, and BALSAM, 1948a, 1948b; HOWE, WEISMAN, and BARTELS, 1949].

Publications and collateral services

Continued services were rendered to land surveyors through correspondence and publications, permitting corrections for the effect of secular change on old compass bearings of property lines. Requests for this information were continuous. Magnetic tests were made for Government agencies respecting sites for laboratories. Data have been furnished to scientists engaged in research on the upper atmosphere and on the deep geology of the Earth's crust. Demonstrations and instruction courses regarding geomagnetic operations and techniques were given to representatives of Federal agencies and of Mexico, Venezuela, Peru, Argentina, Turkey, India, China, Siam, and the Philippines.

Work on publications--"Magnetic declination in the United States, 1945" [DEEL, 1946] continues a series containing tabulated information on the secular change of declination for past years. This edition was improved for easy use and understanding. A general-information pamphlet on topics frequently encountered in correspondence was reprinted [KNAPP, 1949]. Another reprint is in press [HARTNELL, 1930] as are several new publications DEEL and HOWE, 1948; HOWE, 1949a and b; HOWE and HURWITZ, 1949; and EATON, 1949]. Processed reports include the compilation of hourly values for Honolulu for 1937-1938 [KNAPP and HOWE, 1946] and 21 of the half-yearly reports containing small reproductions of the magnetograms for every day [U. S. COAST AND GEODETIC SURVEY].

The collaboration of Survey personnel is reflected in various committee reports and other documents of the International Association of Terrestrial Magnetism and Electricity [HARRADON, 1950; KNAPP, 1950a; McCOMB, 1950; ROBERTS, 1950a and b] and of the Commission on Cartography, Pan American Institute of Geography and History [ANONYMOUS, 1949], and in several articles in print or in press [ADAMS, 1949; HOWE, 1948, p. 228; KNAPP, 1950b; MOODY, 1949; ROBERTS, 1948a, b, and c, 1949].

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Period covered	Observatory				
	Cheltenham	Honolulu	San Juan	Sitka	Tucson
Jan.-June 1946	......	MG-H46.1	MG-J46.1	MG-S46.1	MG-T46.1
July-Dec. 1946	MG-C46.2	MG-H46.2	MG-J46.2	MG-S46.2	MG-T46.2
Jan.-June 1947	MG-C47.1	MG-H47.1	MG-J47.1	MG-S47.1	MG-T47.1
July-Dec. 1947	MG-C47.2	MG-H47.2	MG-J47.2	MG-S47.2	MG-T47.2
Jan.-June 1948	MG-C48.1	MG-H48.1[a]	MG-J48.1[a]	MG-S48.1	MG-T48.1[a]
July-Dec. 1948	MG-C48.2[a]	......	......	......	......

[a] Report in press on June 30, 1949.

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REPORT OF THE COMMITTEE ON RUNOFF, 1949-1950

C. C. McDonald, Chairman

1950	1951	1952
H. L. Cook	W. H. Berry	G. E. Harbeck
Walter V. Garstka	C. O. Clark	C. R. Hursh
Walter T. Wilson	G. R. Williams	C. F. Izzard

The Committee presents as its annual report, a review of current research related to runoff, and a summary of its discussions of terminology as applied to runoff.

W. T. Wilson (44 Loma Road, Redwood City, California)--The Weather Bureau activities in the runoff field during the 1949-1950 year centered largely around its flood and water supply forecasting activities. A new River Forecast Center was inaugurated at Portland, Oregon in January, 1950 to provide service for the Columbia River Basin and adjacent coastal areas. The first custom-made model of the electronic flood routing machine has been delivered and is being tested to determine its electrical and operating characteristics. A large portion of the Bureau's investigations during the year were aimed at developing to the fullest all possible applications of existing techniques but considerable effort was devoted to the problem of developing new methods for short-range forecasting of runoff from melting snow. A technique has been developed which appears to satisfy the requirements but it has not yet been adequately tested. Water supply forecasting activities were continued and the number of forecast points increased to about 300. The Cooperative Snow Investigations, with the Corps of Engineers, continued during the year.

W. M. Berry (Prairie Farm Rehabilitation Administration, Regina, Saskatchewan, Canada)--The Prairie Farm Rehabilitation Administration (P. F. R. A.), a branch of the Dominion Department of Agriculture, is concerned with retiring submarginal lands from active cultivation, establishing community pastures on lands fit only for grazing, reclaiming other lands and developing the limited water resources of the southern portions of the provinces of Manitoba, Saskatchewan, and Alberta. In this development work it can be compared with the work presently being undertaken by the United States Bureau of Reclamation and the Soil Conservation Service.

As it is a development agency, P. F. R. A. is not concerned directly with research activities or gathering basic data, although it does cooperate closely with those services that do gather basic data (meteorologic, hydrometric, and others) and the Dominion Experimental Farms Service.

In March, 1949, the P. F. R. A. Drainage Section was organized to gather information on factors connected with the present and future drainage problems on P. F. R. A. irrigation projects and to institute follow-up work on lands under its control. This work is carried on in southwestern Saskatchewan and southern Alberta. At present the general drainage program is as follows: (1) Information on ground-water levels, fluctuations, and trends, and the source and direction of ground-water movement. Widespread installations of piezometers using 3/8-inch pipe are made to gather this data. (2) Investigations of irrigation practice. These include water application efficiency and infiltration rate measurements, and leaching tests. (3) Canal loss measurement program. The usual methods of current metering, ponding, permeameter and seepage meter measurements are utilized. A small scale canal lining program has been initiated under the direction of the Soil Mechanics Section. Earth materials have been used to date and an installation of asphalt buried membrane lining made. (4) Field measurements of permeability after the method of Kirkham. (5) Limited drainage construction involving deep open drains and pumping from wells has been started. (6) Soils work connected with salinity analyses, permeability studies, and other work is under way. The future work planned in this field is to continue the present program and to initiate field studies and measurements of permeability and ground-water movement in glacial till in irrigated areas.

The P. F. R. A., with the cooperation of the Experimental Farms Service, is obtaining information on the uses of water in a large irrigation district in southern Alberta. With the data being gathered it is hoped that a fairly complete accounting of the distribution of water on this irrigation project may be made.

A few years ago the Lethbridge Dominion Experimental Station set up a small rainfall-runoff station having a drainage area of about 160 acres located close to the city of Lethbridge. The station was primarily experimental to work out the best methods, procedures and types of equipment. This year the P. F. R. A. and the Experimental Farms Service plan to establish, cooperatively, a hydrologic research station having a drainage area of about six square miles, located some 20 mi southeast of Regina.

C. O. Clark (Obras de Riego, M. O. P., Caracas, Venezuela, S. A.)--In Venezuela the knowledge of runoff, past and present, has been extended rapidly in the last year. Most notable is the beginning of a program of stream-flow measurement of the Orinoco River at Ciudad Bolívar. Fifth largest river of the Americas, its low flow is generally more than 300,000 cfs. It is uncrossed by bridges, and more than 150 ft deep at the point selected for measurement, where it is almost a mile wide. A continuous wind further complicates the measurements from an unanchored ferryboat, but excellent progress is being made by the Ministery of Public Works, Irrigation Division, under the direct charge of Fernando Key-Sanchez, Chief of the Hydrology Division. A stage record is available since 1920 and will be a good index of climatic variation in a tropical region when coupled with a knowledge of discharge capacity at each stage. The other source of knowledge of the past is the Lake of Valencia, a land-locked lake in the north central part of Venezuela, which has been falling at various rates for a century and a half, and since 1900 with a mean rate of about 0.2 meters per year. Analysis of its fluctuations is expected to produce general knowledge of variation both in runoff cycles and in evaporation. The American firm, Burns and Roa, Inc., has carried out a stream measurement program on the gold and diamond famous River Caroni during almost two years, but expects to find the gold in a large hydroelectric plant at the Caroni Falls. Robert L. Lowry is here doing some fine hydrology for the firm, R.H. Tipton of Denver, and AGU now has several members in Venezuela. The Venezuelan government is now conducting current-meter measurements at 131 sites each year, and maintains 70 gaging stations of which 41 are equipped with the finest kind of recording devices. These figures are for the Ministry of Obras Públicas, Dirección de Riego, and do not include another fine program of small stream measurement by the Instituto Nacional de Obras Sanitarias. By next year we should have an even more encouraging report on the progress of these enthusiastic newcomers into the field of hydrologic research and observation.

G. Earl Harbeck (U. S. Geological Survey, Washington, D. C.)--As of December 31, 1949, the Geological Survey was obtaining records of discharge at 6049 gaging stations. Funds were requested in the President's budget for an additional 161 stations, largely from the group of 4300 recommended by the Federal Inter-Agency River Basin Committee.

A study of discharge measurement computation methods has been completed. It is contemplated that results of the study will be announced in the near future.

The investigation of water resources in the rice-growing area in southwestern Louisiana, being undertaken in cooperation with the State Department of Public Works, is continuing. A progress report is scheduled for release within the next few months.

Investigations of runoff and sediment impounded by stock-water reservoirs in the intermountain Western States are being continued, and a progress report will be completed within the current year.

The Geological Survey, Bureau of Reclamation, and the Navy Department have commenced a study of water losses from Lake Hefner near Oklahoma City, Oklahoma. Continuous records of contents and total inflow and outflow from the reservoir are being obtained for a volumetric determination of water losses, which is one phase of the entire project.

Studies of verification of values of n for natural channels continued. Values of channel coefficients were determined for about 25 reaches where the discharge was known.

Peak discharges from six small subareas in Maryland drainage basin are being obtained to provide data for design of highway culverts and small bridges.

At the end of the 1949 calendar year the Geological Survey was operating 45 stream gaging stations in Alaska and was making occasional miscellaneous measurements of discharge at about 30 additional locations, principally in southeastern and south-central Alaska with a few stations in the interior near Fairbanks. Reports of interest during the past year include the following: (1) U. S. Geological Survey Circular 44, Large Rivers of the United States, prepared by the Water Resources Division; (2) U. S. Geological Survey Circular 52, Annual Runoff in the United States by W. B.

Langbein and others; (3) Geological Survey of Alabama Special Report 20, Water resources and hydrology of southeastern Alabama, by R. W. Carter, M. R. Williams, P. E. LaMoreaux, and W. W. Hastings; (4) State of Ohio, Dept. of Natural Resources, Division of Water, Bulletin 10, Ohio stream-flow characteristics, by W. P. Cross and R. J. Bernhagen.

G. R. Williams (Knappen Tippetts Abbett Engr. Co., 62 W. 47th St., New York 19, New York)--The Sub-Committee on Flood Frequency, Joint Committee on Floods, American Society of Civil Engineers, completed their labors in November, 1949, and submitted a report to the Society for publication. A wide variety of opinion of flood frequency methods, their use and limitations, made it difficult for the Committee to reach an agreement.

The subject of water resources in general is receiving wide recognition through the President's Temporary Water Resources Policy Commission and the Engineers' Joint Council Water Policy Project.

Williams reports some interesting hydrologic facts regarding Greece, Israel, and Turkey. Most of the sustained runoff in the first two countries comes from limestone springs. The installation of a recording gage on one spring-fed river in Greece revealed a diurnal fluctuation of five to ten per cent in the discharge at very low flows. This phenomenon has been attributed to an alternate filling and emptying of the subterranean caverns through a self-priming syphon action.

A spring-fed stream in Israel indicated a large amount of underground storage. The annual discharge cycle was out of phase with the annual precipitation cycle by about six months. Furthermore, extreme changes in annual precipitation were not fully relfected in the annual runoff until one or two years had elapsed.

Greece is generally considered a dry country because of the climate of Athens, which has an annual precipitation of only about 15 inches. Nevertheless, a record of a large river in western Greece, which rises in the central mountain region, indicated an annual runoff of more than 70 inches. Floods at the gaging station were known to rise 30 ft in less than a day.

Carl F. Izzard (Public Roads Administration, Federal Works Bldg., Washington 25, D. C.)--Attention is called to a paper by W. D. Potter given at the 1949 meeting of the Highway Research Board, entitled "Surface runoff from agricultural watersheds." This paper summarizes the current status of analyses of data on surface runoff from experimental watersheds of the Soil Conservation Service. It emphasizes the distinct differences in the hydrographic behavior of small agricultural watersheds as compared to larger watersheds.

At the same meeting, Tate Dalrymple presented a paper entitled "Regional flood frequency." This paper presents a method by which data from a number of stream gaging stations having different periods of record can be correlated, and discusses the extent to which such studies indicate systematic variation in mean annual flood as a function of the drainage area size and in the ratio of floods for given recurrence intervals to the mean annual flood.

Terminology--During the past year, the Committee has given considerable attention to the question of terminology as related to runoff. Discussion of this subject was included in the annual report for 1949, but no conclusions were given. The Committee has not yet reached agreement on definitions for many of the terms commonly used in the literature. The Chairman at least has concluded that agreement on terminology will not be reached until hydrologists attain more uniformity in their conceptions of the various aspects of runoff phenomena. Areal hydrology is extremely complex and its various phrases are not readily susceptible to arbitrary classification. Many hydrologists have, however, found it convenient and very useful to separate runoff phenomena into various components for purposes of analysis. R. E. Horton's Publication No. 101, Part 1, Analysis of the Hydrograph, is an illustration of this type of classification. The various components, as originally conceived by the analyst, have been assigned names that roughly represent the conception of the original investigator. Later investigators may have taken liberties with these terms, and used them to represent slightly different concepts of essentially the same phenomenon. Many of these changes represent substantial progress and improvement in techniques of analysis. The term may eventually become established in the literature with a firm definition substantially different from that originally used. As long as analytical techniques continue in a state of evolution, therefore, we may expect constant change and a certain amount of confusion in terminology.

Many of the terms commonly used in hydrology represent components of runoff phenomena which are unobservable as physical entities, defy physical measurements, and have poorly defined hypothetical boundaries. Wilson indicates that direct, surface, and subsurface runoff are of this

Table 1--Hydrologic terms and abbreviations from Jahrbuch für der Gewässerkunde des Deutschen Reichs, Berlin, 1937

Symbol	Water levels as given in centimeters			Discharge		Water temperatures as given in degrees centigrade
	Other than tide water regions	In tide-water regions		Amount as given in cubic meters per second	Discharge as given in liters per second per square kilometer	
		Tide-high water	Tide-low water			
	W	Thw	Tnw	Q	q	T
HH[a]	HHW	HHThw	HHTnw	HHQ	HHq	HHT
H[b]	HW	HThw	HTnw	HQ	Hq	HT
MH MH[c]	MHW	MHThw	MHTnw	MHQ	MHq	MHT
M[d]	MW	MThw	MTnw	MQ	Mq	MT
MM[e] (mean minimum)	MNW	MNThw	MNTnw	MNQ	MNq	MNT
N[f]	NW	NThw	NTnw	NQ	Nq	NT
NN[g]	NNW	NNThw	NNTnw	NNQ	NNq	NNT

[a] The highest value ever known or encountered up to publication of the Jahrbuch in 1937. For example, HHT is the highest water temperature that has ever been measured at any one spot.

[b] As compared to HH in column a, which has no time limit, the symbol in this column has a definite time limit. It stands for the highest value encountered during a period of a month, a year, or a number of years; whatever the case may be. It can also stand for the highest value found in any one single month over a period of years. Unless otherwise stated the whole year in question is meant. For example: HW 1926/1935 means that the given figure represents the highest water level encountered during the years from 1926 and 1935. Another example: WiHW 1926/1935 means that the given figure represents the highest water level encountered in all the winters between 1926 and 1935. Another example: Jan HW 1926/1935 means that the given figure represents the highest water level encountered in all of the January months between 1926 and 1935.

[c] The mean high value or the average high value as derived by adding the highest values of each of the years or month, of the series of years or months in question and dividing this sum by the number of years or month, as the case may be. Unless otherwise stated the whole year (every month in the year) in a series of years is meant. For example: MHQ 1926/1935 stands for the mean or average figure for all the highest discharges encountered between 1926 and 1935. Another example: Feb MHQ 1926/1935 stands for the mean or average discharge for all the February months between 1926 and 1935.

[d] The mean value or the average value of all measurements taken over a period of time at any one gaging station. For example: MT 1937 stands for the average temperature as derived from the 365 observations taken in 1937. Another example: MT 1926/1935 on the other hand, stands for the mean or average of all the mean water temperature readings taken between 1926 and 1935. Another example; So. MT 1926/1935 stands for the mean or average of all the mean summer water temperatures between 1926 and 1935. Another example: Marz MT 1926/1935 stands for the mean water temperature as derived from the mean water temperature of all the March months between 1926 and 1935.

[e] Refer to explanation under c.

[f] Refer to explanation under b.

[g] Refer to explanation under a.

type. These terms suggest the separation of the entire discharge of a stream into components according to their routes into the stream. He agrees that if these operations give consistent results within the scope of a particular analysis, they are useful, although confined necessarily to the context within which the operations are performed. He questions the validity of extrapolating the symbolic concepts beyond their context to a natural basin, merely by assuming an analogy between natural events and our interpretation of symbols which represent only some of these events. To extrapolate further to a generality applicable to all basins, and a definition acceptable to many hydrologists is certainly questionable. There is no way of observing how analogous our symbols and nature are. How is one to define the extreme limits of a system of fingering channels? How shallow can water be in the extreme upper ends of channels and be classified as channel storage instead of overland flow or surface detention? Here is a futile effort to define terms by means of undefinables and unobservables.

The Committee desires to emphasize that many terms that have been found useful in relation to the hydrology of runoff are symbolic only, and may be applicable to a basin only in an analytical, and not necessarily in a physical, sense. In a natural basin, infiltration, surface or subsurface flow, and surface detention are extremely complex and interrelated. All degrees and magnitudes of each component may be found in the basin at any given time. Basin averages of these components may have a real meaning analytically, but in a physical sense average values may not be significant. On small test plots, the various components as determined for analytical purposes may approach more closely an actual physical condition and therefore more susceptible to observation and measurement. Here lies a possible danger in the application of plot experiments to natural watersheds.

The Committee finds itself in the same condition of disagreement as to firm definitions as is the profession as a whole. In a general sense, there is fairly complete agreement on most terms but important specific differences still exist. We are therefore not prepared at this time to present recommended definitions, as had been originally intended. We urge all authors, however, to explain specifically the application of the terms used in their particular study and to standardize so far as possible the more common terms.

A. L. Cochran (Office, Chief Engineers, Department of the Army, Washington 25, D. C.)--Herewith is information regarding certain conventions or symbols common in German literature. These are believed to have sufficient merit to bring to the attention of English-speaking hydrologists. As shown in Table 1, the symbols are systematically arranged and readily understood. H indicates Höhe (height) and its several declinations in German; W designates Wasserstand (water level); Q designates water discharge and q designates discharge per unit of drainage area, a familiar notation in English usage; N designates Niedrig (low) and its variants; and M, Mittel (mean).

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Transactions, American Geophysical Union Volume 31, Number 6 December 1950

DISCUSSION OF

"DISTRIBUTION OF SOUND VELOCITY IN A SECTION OF THE EASTERN NORTH PACIFIC" by ERNEST R. ANDERSON

[Trans., v. 31, pp. 221-228, 1950]

Karl Dyk (Box 591, Tulsa, Oklahoma)--It is interesting to compare Anderson's data with those obtained by the U. S. Coast and Geodetic Survey incidental to an investigation of sound transmission in deep sea water in November 1933. This work was done in the Santa Barbara Islands Basin located just off the northeastern limit of Anderson's observations. This basin is about 45 mi long and 30 mi wide, the water depth reaches a maximum of 1050 fm, and the surrounding shoals are generally from 100 to 300 fm in depth.

The 1933 data gave a computed velocity at the sound channel axis of 4865 ft/sec and 4933 ft/sec at the top of the sound channel, a difference of 77 ft/sec. The angle of the limiting ray was reported as 10.1°. The width of the sound channel was not determinable as the velocity at the bottom was less than the surface maximum. The close agreement with conditions 15 yr later is remarkable. A secondary sound channel between depths of 90 and 150 fm was found in the 1933 work, and transmission along this layer was observed.

Anderson's introductory reference to Ewing implies that Ewing was the first to recognize that transmission to great distances along the principal sound channel was possible. Attention was specifically called to this property in the report of the 1933 work [SWAINSON, McILWRAITH, and DYK, 1934], of which Ewing was sent a copy at the time.

References

SWAINSON, O. W., C. G. McILWRAITH, and K. DYK, The velocity and ray paths of sound waves in deep sea water, U. S. Coast and Geodetic Survey, unpublished report, 1934.

Ernest R. Anderson (U. S. Navy Electronics Laboratory, San Diego, California, Author's closure)--As indicated by Dyk it is indeed interesting to note the agreement between the present observations and those made 15 yr earlier on the sound velocity at the deep channel axis and at the top of the channel. However, the Swainson, McIlwraith, and Dyk paper indicates that the depth of the channel axis was approximately 850 m. This depth is considerably deeper than any observed by the author.

The following is quoted from the paper by Swainson and others: "It should be noted here that if the source is in, say, the 450-fm constant velocity layer, direct paths to subsurface points at great distances are theoretically possible." This statement certainly recognizes the long range sound transmission properties of the deep sound channel by Swainson and others, as early as 1933.

In a mimeographed report published in 1945 [EWING and WORZEL], Ewing "proposed" the establishment of a system of communication utilizing the long range sound transmission property of the deep sound channel. In 1944 tests of long range sound transmission were conducted. These tests resulted in ranges of about 900 mi in the Atlantic Ocean. As a result of these tests it was suggested that a network of receiving hydrophones be established to locate sound sources.

It was not the author's intention to imply that Ewing was the first to recognize the transmission properties of the deep sound channel but only to indicate that Ewing verified this property and "proposed" that it be utilized in the establishment of an air-sea rescue system.

Reference

EWING, M., and J. L. WORZEL. Long range sound transmission, Interim Report No. 1, Woods Hole Oceanographic Institution, August 25, 1945.

Transactions, American Geophysical Union Volume 31, Number 6 December 1950

DISCUSSION OF

"PULSATIONAL TRANSPORT OF SAND BY SHORE AGENTS"

by W. C. KRUMBEIN and L. E. OHSIEK

[Trans., v. 31, pp. 216-220, 1950]

John W. Handin (University of California, Los Angeles, California) and **John C. Ludwick** (Scripps Institution of Oceanography, La Jolla, California)--The very interesting paper of Krumbein and Ohsiek brings to mind three types of pulsational sand transport which we have observed in recent studies of Southern California beaches.

The relative capacities of longshore currents can be estimated by assuming that the capacity, Q, is proportional to the longshore component of the energy of refracted waves at the plunge zone [HANDIN and LUDWICK, 1950].

$$Q \alpha eW \sin 2\alpha$$

where e = relative wave energy per unit length of wave crest or the shallow water wave energy divided by the deep water wave energy, W = wave work factor or the total work done by all waves of a given period and direction during an average year, α = angle between a wave crest and the shoreline.

The first sort of pulsational transport is probably typical of crenulate shorelines where there is a variation from place to place in e and α, as a result of differences in wave refraction due to local submarine topography. For a given set of wave conditions, lasting for a few days, the direction of wave approach in deep water and the wave work factor, W, are more or less constant; but local submarine topography materially affects e and α, so that there are differences in longshore current capacity along the shoreline at any given time. A headland, for example, can act as a natural "jetty" where the capacity of the currents is reduced. At the same time other places on the shore can be the focus of relatively strong current action. There is then local deposition at the headlands and local erosion in regions of high current capacity. With a change in prevailing wave conditions, sand can move around the headlands to be deposited in the former erosion zones. The period of pulses of this sort is a few days, and the amplitude depends upon the degree of wave refraction and therefore upon the relief of the nearshore bottom topography.

The second sort of pulsational transport can occur even along straight beaches and is the result of seasonal changes in prevailing wave conditions. In Southern California, waves that are most common during the summer months have a relatively low average wave work factor. These waves also approach nearly normal to the shoreline, so that α is small. Winter waves, on the other hand, have a relatively high wave work factor, and they approach at high angles to the shoreline, so that α is large [SCRIPPS INSTITUTION, 1947]. Accordingly longshore currents prevailing during the winter have relatively high capacities, and the beaches retrograde. During the summer season capacities are low; the beaches prograde. (A part of this seasonal effect with a quite different cause is due to a movement of sand on and off the beaches in a direction normal to the shoreline [SHEPARD and LAFOND, 1940].)

The third type of pulsational transport depends not upon the variability of transporting power of the longshore currents but upon the discontinuous supply of sediment from the source areas. In Southern California appreciable quantities of terrigenous sediment are added to the littoral zone by streams only during times of flood. At other times there is little or no runoff, and the contribution of sediment from sources other than streams is negligible. Floods occur only once in several years.

In Southern California at least it seems that longshore sediment transport is always pulsational in nature. Indeed there may be several pulses of different periods and amplitudes superimposed: (1) short period local pulses lasting a few days, (2) seasonal pulses with a yearly period, and (3) long period pulses occurring every few years.

References

HANDIN, J. W. and J. C. LUDWICK, Accretion of beach sand behind a detached breakwater, Tech. Mem. No. 16, Beach Erosion Board, 1950.

SCRIPPS INSTITUTION OF OCEANOGRAPHY, A statistical study of wave conditions at five open-seå localities along the California coast, Wave report No. 68, 1947.

SHEPARD, F. P. and E. C. LAFOND, Sand movements along the Scripps Institution pier, Amer. J. Sci., v. 238, pp. 272-285, 1940.

W. C. Krumbein (Northwestern University, Evanston, Illinois, Authors' closure)--In our original paper, it was our intention to emphasize the rather sudden movement of a body of sand which had accumulated in a trapping locality. It is interesting that Handin and Ludwick extend the meaning of the term to include intermittent transport even along straight uninterrupted shores.

With this enlarged meaning, it is also true that movement of sand along the western shore of Lake Michigan falls into similar patterns of short period local pulses lasting a few days, and seasonal pulses with a yearly period.

From a short period point of view, observations show that waves approach alternately from the northeast and southeast, sometimes with a calm between. The sand is accordingly shifted southward or northward, with intervals of rest during the calms. On a seasonal basis, there is dominance of northeast waves from fall to spring, with smaller southeast waves generally dominating during summer. The net statistical movement of sand is accordingly southward, with short reversals of direction, interspersed with intervals of no movement.

Under the enlarged meaning of pulsational transport, it appears that a closer analysis may be made of sand movement along shores, with a consequent better understanding of changing beach characteristics, and a better basis for evaluating the influence of engineering structures.

DISCUSSION OF

"INTERPRETATION OF SNOW SURVEYS"
by WALTER U. GARSTKA

[Trans., v. 30, pp. 412-430, 1949]

H. G. Wilm (Southern Forest Experiment Station, New Orleans, Louisiana)--This article is an excellent example of recent efforts that have been made to work out improvements in the correlation of independent variables with water yields. Garstka has employed a common-sense approach to this problem, and has evidently succeeded in accomplishing worth-while reductions in forecasting errors.

On page 417 Garstka says that "only the accumulation of records in the future can disclose which of these two sets of lines most nearly reflects the relationship of snow storage to runoff in the drainage basin above Jackson Lake." Judging from Figure 10, a change in this relation does seem to have occurred in the 1930's. If so, perhaps it is due to some progressive time trend which cannot be removed. In that case the forecaster's best course is to adapt his technique to the presence of such a trend, minimizing its effect on the forecasts. This can be done by employing a progressive forecasting equation, predicting runoff only one year ahead of the last year of record. In order to keep errors as small as possible, the earliest years of record should be progressively dropped off in the same operation, retaining only enough to keep the sampling error of the regression equation within reasonable limits.

In this particular case, though, it seems more likely that the change in relation occurred, as Garstka says, "when the snow-course network was incorporated into the West-wide system." Perhaps some relocation of snow courses, revisions in measuring techniques, or other alterations were made in 1936 and affected the basic data on snow storage. If this is the major cause of the change, the best available course of action is to base forecasts only on the series of years since 1935: The present shortness of record will soon be remedied as the years accumulate, and even now the resulting errors are probably smaller than those due to including those years preceding the changes in the snow courses. Any possible adjustments of earlier years are necessarily subjective to some extent, so that the results are not likely to add real precision to the forecasts; though they may be employed to help estimate the magnitude of residual forecasting errors. This may be done through conventional covariance analyses.

In this article Garstka worked with snow-course data in developing forecast techniques, while other authors have concentrated on the use of precipitation records obtained in various types of snow-and-rain gages. There seems to be some difference of opinion at present, as to which approach offers greater promise.

From a purely logical viewpoint as well as from experience, it seems to this writer that both have merit, but that the use of either must depend on conditions in the particular watershed for which forecasts are desired. On one watershed there may be a good deal of winter melting, with movement of water from the column of stored snow into the soil. Even though this may not increase stream runoff at the time, it replenishes soil-moisture deficits and is therefore likely to affect subsequent water yields. In this case snow-course data would fail to give the whole story, and precipitation records would be better; assuming, of course, that reasonably precise data on winter precipitation can be obtained.

At the other extreme are many watersheds in the high western mountains, where winter melting is negligible but sublimation and evaporation of stored snow may induce substantial losses of water. There snow-course data would give more precise estimates of the amounts of water available to produce runoff again, if the courses are so placed as to give representative estimates of watershed snow storage.

It seems evident, if this reasoning is true, that most watersheds combine both of these phenomena to varying degrees. Hence the best estimates of runoff should be obtainable by some combination of precipitation and snow-course records, with the relative weight of each determined by rational and empirical analyses. Solution of this problem is, of course, one of the objects of current research at snow laboratories in the West.

Walter U. Garstka (Hydrology Division, Branch of Project Planning, Bureau of Reclamation, Denver, Colorado, Author's closure)--In regard to H. G. Wilm's discussion, the length of records selected as the basis for a forecast relationship depends to a considerable extent upon the use to be made of the forecast. Project planning applications require consideration of the longest records available, in order to provide information on the magnitude and frequency of recurrence of years of extremely small and large water yield volume. On the other hand, operational usage may be more efficient if shorter lengths of the more recent years of record only are used in a forecast relation, as the recent years tend to reflect better the current conditions in relationship to long-term non-harmonic trends in climate and precipitation.

This paper presents a straightforward method of calculation from snow-survey data and watershed area-elevation relationships of snow-water equivalent on a watershed. Numerous instances of the application of this method to a forecast computation using snow-survey data alone have uniformly yielded a better forecast relation as evaluated statistically than has been attained through the use only of arithmetic averages of snow-survey data. Work is now under way in which elevation-weighted snow water equivalents are being used together with precipitation and other data in a multiple-correlation calculation of a forecast relation.

The distinction between the so-called snow-survey-based and rain-gage-based forecasts is purely artificial. It is to be kept in mind that snow is a form of precipitation resulting from the influx of water vapor transported by the passage of air-masses. Proponents of the rain-gage-based, seasonal, water-yield forecasts in the western United States should remember that the water yield comes from the melting of the accumulated snows. As both Wilm and Linsley and Kohler point out, some combination of precipitation-gage data and snow-water equivalents offers promise of yielding superior forecasts for certain drainage basins. This promise has already been fulfilled in numerous in-service project planning and operational forecasts made by the Bureau of Reclamation.

The practical problem is one of determining what particular combination of all the data available is capable of yielding the best forecast for a specific drainage basin. Thus, techniques of statistical analysis have been brought to use as aids in the search for the best possible forecast. However, the application, by rote, of procedures extracted from textbooks may place pitfalls in the path of the forecaster, who is expected to treat his data and select his procedures with discernment. Thus, LINSLEY and KOHLER [1949], use a method based upon the weighting of individual stations. Such a system of selections usually discloses on the first trial a series of negative regression coefficients for various stations. By rule, stations possessing negative regression coefficients are usually rejected, and the remainder used in a recomputation. If the rejects from the first trial are used in a new computation, it usually develops that many of them exhibit positive regression coefficients.

This means that the stations have been assigned, at some point in the analysis, an unnatural characteristic which is an outgrowth of the statistical procedure selected by the forecaster. It is not logical to assume that any precipitation gage or snow course can possess a negative regression coefficient with reference to water yield. The relationship can only be either zero or some positive value, as a negative regression coefficient means that the greater the precipitation the less the water yield. As this is patently hardly possible, the Linsley and Kohler method proposes the rejection of basic data to extricate the forecaster from his mathematical morass.

With reference to the next to the last paragraph on page 294 of the Transactions, volume 31, Linsley and Kohler are referred to the two opening paragraphs of this paper.

A fundamentally sound application of the multiple correlation statistical method to the derivation of seasonal water yield forecast relations is that by FORD [1949], as presented at the 16th Annual Meeting, Western Snow Conference, Reno, Nevada, of April 1948. Ford's method weights seasonal rather than individual stations, thus making it possible to introduce in a natural manner the influence of precipitation, including snow and temperature among other factors as they occur in the pregression from the autumn, through winter and spring, into the summer. The use of small number of variables yields a large number of degrees of freedom, which is used in expressing the strength of the forecast relation by the evaluation of both $\overline{R}$, coefficient of multiple correlation, and $\overline{S}$ the standard deviation.

In conclusion, the recent articles and the volume of the discussions is a reassuring indication of the vitality of the subject of seasonal water yield forecasting, which offers promise of valuable advancements yet to come.

References

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FORD, P. M., Multiple correlation in forecasting a seasonal runoff, Engr. Monograph 2, Bureau of Reclamation, Denver, Colo., April 1949.

DISCUSSION OF

"ANNUAL FLOODS AND THE PARTIAL DURATION FLOOD SERIES"
by W. B. LANGBEIN

[Trans., v. 30, pp. 879-881, 1949]

Ven Te Chow (Hydraulic Engineering Laboratory, University of Illinois, Urbana, Illinois)--The writer is interested in finding from this paper a similar idea which he had in mind when engaging in a statistical study of hydrologic data, a part of the Highway Drainage Research Project being carried out in the Department of Civil Engineering, the University of Illinois. However, a complete presentation of the study will be reserved for future publications, and only fragments of thought are discussed here.

In treating hydrologic data for the study of their frequency of recurrence, two phases of study are generally met. One is the frequency of recurrence for the observed distributions, and the other is the corresponding frequency of recurrence for the theoretical distributions of best-fit. The former is usually required for the purpose of plotting observed data, and hence is called the "plotting positions," a term used by FOSTER [1934, p. 1217]. The latter is treated by the mathematical theory of probability, and generally serves as a theoretical interpretation of the observed phenomena.

A correct determination of plotting positions has been a moot question and caused a great deal of discussion. Many methods for computing plotting positions have been proposed. The one, $p = m/nN$, used in the paper is after the California method [THE CALIFORNIA DEPARTMENT OF PUBLIC WORKS, 1923]. However this does not affect the conclusion of the paper, because the treatment given in the paper was finally centered on the expectancy ϵ which is general for all cases.

If T_p is the recurrence interval of hydrologic events in partial duration series, and T_a is the recurrence interval of hydrologic event in annual maximum series, then, according to the paper

$$T_p = 1/\epsilon \qquad (1)$$

and

$$T_a = 1/(1 - e^{-\epsilon}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The difference between these two recurrence intervals with respect to T_a is

$$(T_a - T_p)/T_a = (e^{-\epsilon} + \epsilon - 1)/\epsilon \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where ϵ is related to T_p and T_a by (1) and (2) respectively.

From Figure 1, which shows the plotting of $(T_a - T_p)/T_a$ against T_p, it is evident that a difference of about ten per cent corresponds to a five-year recurrence interval, and a difference of about five per cent corresponds to a ten-year recurrence interval. In ordinary engineering practice of such nature, a five-per-cent difference is tolerable, as it has been recognized by the engineers of the U. S. GEOLOGICAL SURVEY [1947, p. 6] that the two methods give essentially identical results for intervals greater than about ten years. Similar conclusions would be obtained by plotting $(T_a - T_p)/T_p$ against T_a or T_p. Figure 1 also shows that the difference is always positive, and hence $T_a > T_p$ is evident.

From a theoretical point of view, a recognized distinction between the two methods is that the annual maximum series forms a complete series, but the partial duration series does not; hence, a mathematical analysis of the latter cannot be readily made. GUMBEL [1941] has utilized the theory of largest values [FISHER and TIPPETT, 1928] to interpret the theoretical distribution of annual maxima. By this method the recurrence interval of the annual maximum series can be expressed by

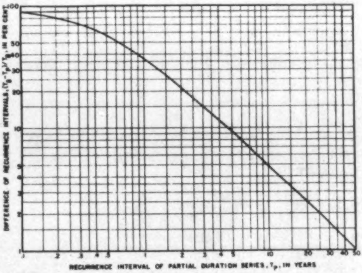

Fig. 1--Relationship of $(T_a - T_p)/T_a$ to T_p

$$T_a = 1/(1 - e^{-e^{-x/c}}) \ldots\ldots (4)$$

in which $x = a + y$, c and a are parameters, and y is the value of annual maximum. Comparing (4) with (2), it is obvious that the expectancy of recurrence is

$$\epsilon = e^{-x/c} \ldots\ldots\ldots\ldots (5)$$

Substituting (5) in (1), the recurrence interval in partial duration series becomes

$$T_p = e^{x/c} \ldots\ldots\ldots\ldots (6)$$

By substituting $x = a + y$ in (6) and modifying

$$y = c \log_e T_p - a \ldots\ldots\ldots (7)$$

which will give a straight-line relationship of y and T_p when plotted on a semi-logarithmic graph paper. Therefore, if Gumbel's method of using the theory of largest values in annual maximum series is mathematically adequate, then the conclusion shown by (7) should explain the legitimate use of semi-logarithmic plotting in the empirical method of partial duration series.

The related objection arose in the partial duration series method due to its inclusive use of floods of high magnitude but next to the peak value, as stated in the paper, should be judged by the nature of the designed structure, because the damage caused by flooding is sometimes counted on the repetition of flood rather than on the peak flow. Consider the design of a culvert in which damage or destruction will be rapidly and economically repaired and then soon again exposed to risk. Similarly for the case of highway in which the loss due to traffic interruption as a result of flooding will be weighed by the number of floods and the vastness of flooding which is largely played by the associated peak flows. Therefore, in these and other like cases, the objection becomes an apparent approbation.

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Walter B. Langbein (U. S. Geological Survey, Washington, D. C., Author's closure)--We are indebted to Chow for his constructive demonstrations of the relationships between the annual flood and partial duration series. His development of the simple logarithmic relationship between discharge and recurrence interval in the partial duration series is particularly instructive and original.

The flood-frequency compilation of the Geological Survey will give complete data for both series. However, studies and analyses will be carried out only on the annual flood series, chiefly because of (1) its simplicity, (2) the theoretical point that it forms a complete series and (3) the practical point that results can be duplicated or verified by different analysists.

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REVIEWS, ABSTRACTS, AND BIBLIOGRAPHY

REVIEWS AND ABSTRACTS

LINSLEY, RAY K., MAX A. KOHLER, and JOSEPH H. L. PAULHUS, Applied hydrology, McGraw-Hill, New York, 689 + xiv pp., 1949.

Applied Hydrology is the most comprehensive of the new hydrology books, both in scope and treatment. It contains 22 chapters and three appendices. The subject index has optimum detail, and is carefully worked out. The fairly complete name index has nearly 400 citations. In general, the writing is excellent and lucid, and terms are well-defined. The small number of errors for a first printing (1949) indicates a careful job of proofing.

The subject is introduced in the first chapter by a brief description of the history, scope, and application of hydrology.

The second chapter deals with climate, starting with a description of the theoretical planetary circulation. The Bergeron cyclone model is shown, also mean pressure maps and some of the Bowie and Weightman storm tracks. Physiographic influences on climate are described briefly, though nothing is said of classification of climate, such as by Köppen or Thornthwaite. Inasmuch as an increasing number of hydrologists use synoptic weather maps, this chapter might have been a convenient place to indicate their nature and use. A brief discussion of upper air observations would have been helpful, particularly in regard to the general circulation.

Temperature is the subject of the third chapter, which starts with a discussion of heat exchange in the lower atmosphere. The forms of relationships for interpolating temperature and precipitation data, and the effects of varying instrument exposure are discussed concisely. Gravity drainage and stratification of cold air in valleys are referred to, but nothing is said of their important winter counterpart, which characteristically produces corresponding though deeper inversions. The discussion of cycles is realistic, citing the diurnal and annual as the only cycles having established validity and importance in meteorology. In general, as each element is introduced in the book, there is a logical discussion of its observation and its distribution in time and space, both large and small scale.

The subject of Chapter 4 is atmospheric humidity. Several formulas are given for the density of moist air, without indicating that a good working value is about 0.0012 for either moist or dry air for ordinary conditions near sea level. A set of maps shows the areal distribution of precipitable water, by seasons, in the United States. The discussion of orographic influences ignores the effects of leeward and windward exposures near large moisture sources.

Winds are discussed in Chapter 5. Considerable space is given to theoretical steady-state formulas having limited application to hydrology. Under the subject of localized wind phenomena are discussions of tornadoes and foehns. Later, under the subject of geographical variation, valley and sea breezes and the effects of exposure are described. There is a statement relating the limit of effects of surface friction to the gradient level and to heights of 2000 ft, though the reader may wonder how much of this is definition and how much is observation. A set of maps shows the prevailing seasonal wind vectors at selected elevations above sea level at various stations in the United States.

The chapter on precipitation starts with a good discussion of its origin and formation in the atmosphere. A section entitled "types of precipitation" describes cyclonic, convective, and orographic precipitation. The description of operation, site selection, and reduction of records of precipitation gages lacks the degree of detail given later to measuring streamflow. Among instrumental errors cited is a two per cent factor ascribed to displacement of the measuring stick. This error is in fact a little less than one per cent, and is about compensated for by the unmeasured wetting of the surface of the funnel and receiving cylinder. The authors present good information on the effect of gage density on variation in estimated depths over various areas. The discussion of adjustment of precipitation data is detailed and fairly objective. There is a detailed example of duration-area-depth analysis. There are many useful diagrams and maps showing average and extreme precipitation and its variation in time and space. It is hoped that future printings will show the periods of record for the maximum recorded precipitation at first order stations shown in Table 6-2. There is no reference to fog drip or to deposition of dew, though considerable space is given later to interception, which may be of no greater importance.

Snow, ice, and frost are discussed in Chapter 7. The discussion of measurement of deep snow is good, but fails to cite U. S. Department of Agriculture Miscellaneous Publication 380 as a source of more detailed explanation. In the discussion of anchor-ice formation, water is said to be opaque to most radiation, whereas, actually and relevantly, water is largely opaque to long-wave radiation. In matters of this sort, it would have been helpful for the authors to have referred to and cited such books as Dorsey's "Properties of ordinary water substance," and Sverdrup's "Oceanography for meteorologists." Other omitted citations are the proceedings of the Pennsylvania State Hydrology Conference and the Central Snow Conference, both in 1941. On page 140, in a discussion of the water-holding capacity of snowpack, it is suggested that most of a two-inch rain was discharged through many feet of snow. Examination of the stream-flow record at Cisco definitely confirms, not only for this storm, but also for many others, that snowpack has very little residual capacity for storing rain. Instead of saying that insolation penetrates only about 12 to 18 inches of snowpack, it would be more precise to cite Lambert's or Beer's exponential law, and state that absorbed insolation halves about every two inches of penetration into the snowpack.

Evaporation and transpiration are the subject of Chapter 8. In general the chapter presents a good description of methods for measuring evaporation, and for estimating it by theoretical and by empirical formulas. Figure 8-1 shows a high joint correlation between pan evaporation and air temperature and time of year.

Chapter 9 discusses stream flow. In the introductory paragraph is an important statement that all other (than stream flow) measurements in the hydrologic cycle are, at best, only inadequate samples of the whole. In quoting this statement it does not suffer from lack of context, but typifies a realistic attitude which becomes increasingly evident later in the book. Double mass curves of stream flow, methods for extending rating curves, and other techniques are discussed. Tables 9-10 and 9-11 show average and extreme flows for various periods for a good selection of stations in the United States. The chapter goes into optimum detail in describing measurement of stream flow and methods of working up stage-discharge relations.

In Chapter 10 physical characteristics of drainage basins are discussed, and methods are given for deriving many topographic parameters. Playfair's law of streams is set forth with some emphasis, but nothing is said of the quantitative bifurcation ratio and its application. There is considerable well-selected material on geomorphology, with emphasis on alluvial streams.

Chapter 11 is devoted to surface retention and detention and overland flow. The authors probably did about as well as they could with the traditional fictions and "reasonable" values of the many indeterminate factors which Horton and others have studied rather inconclusively.

Soil physics is the subject of Chapter 12. The discussion of hygroscopic coefficient, wilting point, field capacity, and moisture equivalent, is critical, emphasizing the continuous nature of soil-moisture energy, and the arbitrary nature of such terms. Colman's recent work on soil moisture meters is cited, but there is no reference to Bouyoucos. A section on soil temperature, pages 302-308, interrupts the continuity between soil moisture and infiltration. A smattering of heat conduction theory omits reference to Fourier, and does not cite sources such as Ingersoll and Zobel, and Carslaw. Baver's work is cited in part. The importance of organic material is somewhat neglected.

Sedimentation is the subject of Chapter 13, in which both erosion and transportation are presented. The material is largely analytical, lucidly described, though rather uncritically selected. On page 334 the mean shear force required to "start" bed-load movement is given as an arbitrary limit in the distribution of velocities. The 0.3 per cent is erroneously applied to only one tail of the distribution. There is no reference to changing cross-section of alluvial streams as a useful measure of soil movement.

The ground-water chapter is largely descriptive. There is no reference to the recent work of Jacob or Kirkham, to salinity control, or to agricultural drainage. Otherwise the brief treatment is rather comprehensive.

In the introduction to Chapter 15, hydrograph analysis, the authors state the practical impossibility of measuring the water following each path or route to the channel. It is gratifying to see a textbook presenting such a realistic view of separating hydrograph components. Table 15-1, from an undisclosed source, (the World Almanac gives better information on the subject) shows the percentage of surface-water area for each state. It is evident that irrelevant bodies such as Chesapeake and Delaware Bays are included.

In Chapter 16, runoff relations, as well as in the previous chapter, there is no application of the hypothetical and plot material of some of the earlier chapters. There is a good explanation of short-period and seasonal relations, presented objectively and in optimum detail. One of the few shortcomings is the reference on page 418 to a 1947 paper by Linsley, in which he "shows" the conformation of areal distribution of storm precipitation to the mean annual pattern in certain mountainous regions. This technique has been used by Pacific Coast hydrologists for several years, and is referred to in the published Sacramento Report of the Hydrometeorological Section, completed in 1942. The lack of reference to ground-water observation wells as an aid to hydrologic analysis is noted.

Chapter 17 covers runoff distribution, mostly with respect to time, and presents in straightforward manner standard methods for deriving and manipulating unit hydrographs. The material on snow reflects the present somewhat speculative state of published knowledge on the practical aspects of the subject.

The chapter on waves is largely theoretical, including seiches, tides, and bores, but there is no discussion of backwater curves. Figures 18-14 and 18-15, showing forecast and observed tidal stages, will please weather forecasters who are occasionally annoyed by disparaging comparisons of their work to the precise work of astronomers.

Chapter 19 covers stream-flow routing. Figure 19-32 is very instructive, showing the relative effects of various combinations of x and K routing coefficients.

Chapters 20 and 21, design and operation of flood control and multiple-purpose works, include many controversial issues, on which the authors have given their opinions in a convincing and forthright manner.

Chapter 22 covers river forecasting as an essential phase of flood control.

The three appendices explain techniques of graphical correlation analysis, show sources of hydrologic data, and present tables of useful physical constants.

As part of the traditional duty of a reviewer, this writer has cited some of his criticisms of the book. Another duty of a reviewer is to present an appraisal, which, in the case of this excellent book, it is hoped will not be construed too much in terms of these criticisms. It may be appropriate to remind readers that technical books seldom enjoy large sales, and that the financial rewards are hardly worth the cost to these authors of about three years of normal home life. What prestige they have gained is richly deserved for what must be acknowledged as one of the most important contributions that has been made to hydrology.

WALTER T. WILSON

HAMILTON, E. L., and P. B. ROWE, Rainfall interception by chaparral in California, Calif. Dept. of Natural Resources, Div. of Forestry, in cooperation with U. S. Forest Service, Calif. Forest and Range Expt. Sta., 43 pp. + 16 illus., Bibl., 1949.

Determination of rainfall not reaching the soil, called interception loss, is important in the solution of water-supply and flood-control problems. Interception loss in shrub types of vegetation was measured at three locations in California. On one area in the Sierra Nevada foothills in central California 81 per cent of an average annual rainfall of 42 inches reached the soil by falling through and dripping from the brush cover, 14 per cent reached the soil by flowing down the stems, and five per cent was lost as direct evaporation from the vegetation. On another area in the same vicinity with a different type of brush cover, 62 per cent of an average annual rainfall of 38 inches reached the soil as throughfall, 30 per cent as stemflow, and eight per cent was lost by interception. In the San Gabriel mountains of Southern California, 81 per cent of an average annual rainfall of 22 inches reached the soil as throughfall, eight per cent as stemflow, and 11 per cent was lost by interception. Amounts of throughfall, stemflow, and interception loss varied directly with storm size. However, the proportion of interception loss varied inversely with storm size. An equation of interception loss for storms of more than 0.3 inch is given for each study area. The interception process is explained by analysis of typical storms during which running records were made of rainfall, throughfall, stemflow, and interception storage.

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NOTES AND PERSONALIA

NOTES

The work of the National Scientific Register--The National Scientific Register, recently organized in the Office of Education under the sponsorship of the National Security Resources Board, has under way the most comprehensive registration of American scientists and technologists ever undertaken. The work of sending out forms has already begun. It is being accomplished through the assistance and cooperation of the various scientific and professional societies. The American Geophysical Union is participating actively. It is anticipated at this time (November 20, 1950) that before the end of 1950, forms for geophysicists and those in allied fields will be sent out. The purpose of the Register is two-fold: (1) What are the characteristics of the supply of scientific or technological manpower? (2) What will be the requirements for scientists and technologists in all phases of mobilization?

This project has been given high priority in view of the critical role of science in the last war, and in recognition of the fact that our security depends, in case of a future general mobilization, to an important degree, on the effective utilization of our scientific skills. It is therefore urged that all who receive the registration questionnaires fill them in and return them promptly.

Development of a Union of International Engineering Organizations--A meeting was held in Paris, October 9-13, 1950 by representatives of 15 international engineering organizations under the sponsorship of UNESCO to organize a Union of International Engineering Organizations. A draft constitution was formulated, with the understanding that the Union would come into being upon the subscription of ten of the organizations to the Union. The main objectives of the Union are: (a) To coordinate, by common agreement, the activities of the member organizations, and in particular the program and the dates of international congresses; (b) to take all useful steps for the moral and material support of the member organizations; (c) to receive proposals and to make recommendations thereon with a view to helping the formation of new international organizations in fields not effectively covered by existing organizations; (d) to further mutually helpful relations among the member organizations and similar organizations and also relations between the member organizations, the UN and their Specialized Agencies. The fifteen bodies represented were: International Association of Bridge and Structural Engineering; World Power Conference; International Commission of Large Dams of the World Power Conference; International Commission of Illumination; International Conference on Large Electric Systems; International Gas Union; International Association for Hydraulic Research; International Society of Soil Mechanics and Foundation Engineering; International Institute of Welding; Permanent International Association of Navigation Congresses; Réunion Internationale des Laboratoires d'Essais et de Recherches sur les Matériaux et les Constructions; International Commission on Irrigation and Canals; International Railways Congress Association; Permanent International Association of Road Congresses; and International Federation of Surveyors. Among the persons elected by the organizing groups to constitute the Executive Council of the provisional Union is Lorenz G. Straub, who was elected one of the three Vice Presidents.

Arno Atoll project--An extensive environmental study of an atoll was begun in June 1950 by 13 scientists under the auspices of the Pacific Science Board of the National Research Council, and the U. S. Office of Naval Research. Arno Atoll in the Marshall Islands was selected for the study. Among the investigators are Doak Cox (on hydrology), John Wells (on reef geology), R. W. Hiatt and Donald Strasburg (on marine zoology), Gerald Wade (on geography), Earl Stone (on soil science), and Donald Squires (on general geology).

Cruise of the Hugh M. Foster--The Hugh M. Foster of the U. S. Fish and Wild Life Service, made a six-weeks summer cruise taking hydrographic sections across the equatorial countercurrent systems to compare with similar sections taken on a winter cruise. The purposes of the investigations are to determine the position and extent of the counter current, the degree of upwelling along its boundaries, and the effect of the current on the biologic productivity of the region. Special weather observations were made for the U. S. Weather Bureau.

New maps of the U. S. Geological Survey--Two new maps showing the status of Federal topographic mapping are available upon request to the U. S. Geological Survey, Washington,25 D. C. The Survey also has issued a new edition of their circular, Maps of Alaska, which is also available upon request.

New Institute of Geodesy, Photogrammetry, and Cartography established at Ohio State University--An Institute of Geodesy, Photogrammetry, and Cartography has been established in Ohio State University which will offer undergraduate and graduate work in these fields. The functions of the Mapping and Charting Research Laboratory of the Engineering Experiment Station will be closely correlated with the activities of the new Institute. George H. Harding, Director of the Laboratory, will also serve as Director of the Institute.

PERSONALIA

Francis Birch of Harvard University was named the third recipient of the Arthur L. Day Medal of the Geological Society of America in recognition of outstanding contributions in the application of chemistry and physics to the solution of geologic problems.

Archie Blake has resigned his work as Government statistician and is serving as Treasurer, and Consultant in Applied Mathematics with the Mechanical Research Corporation of Chicago.

Kenneth G. Boling, Petroleum Geologist, has resigned as Assitant Manager of the Land and Geological Department for Sam D. Jarvis, and opened offices in Evansville, Indiana, where he represents some Michigan independent oil interests.

Warren J. Brown, formerly of the Department of Meteorology of New York University, is now engaged in research as a ballistic meteorologist of the U. S. Naval Ordnance Test Station at Inyokern, California.

E. Bucher, former Director of the Swiss Institute for Snow and Avalanche Research has taken up duties on the staff of the Snow, Ice, and Permafrost Research Establishment in St. Paul.

Earl Church, Professor of Photogrammetry of Syracuse University, retired, is serving as Non-Resident Consultant of the Mapping and Charting Research Laboratory of Ohio State University.

Burton S. Grant has been named Chief Engineer of Water Works and Deputy General Manager of the Department of Water and Power, City of Los Angeles.

Weikko Heiskanen, Director of the Isostatic Institute of the International Association of Geodesy, IUGG, and Director of the Geodetic Institute of Finland, has been appointed Resident Consultant of the Mapping and Charting Research Laboratory of Ohio State University for a term of one year.

E. Donald Kennedy has resigned his position with the Engineering and Industrial Experiment Station of the University of Florida, and taken up duties with the Goodyear Aircraft Corp. in Akron as an electronics engineer in the Aerophysics Division.

Walter D. Lambert, Geodesist of the U. S. Coast and Geodetic Survey, retired, and Bowie Medalist in 1949, has been appointed Non-Resident Consultant of the Mapping and Charting Research Laboratory of Ohio State University.

Edmund F. Schulz, Hydraulic Engineer, Bureau of Reclamation, Boulder City, Nevada, is on leave to undertake research work at Colorado A. and M. College.

Kenneth G. Smith has accepted a position as Instructor in Geology at the University of Michigan.

Willard M. Snyder has joined the staff of the Tennessee Valley Authority on work in hydrology, meteorology, and hydraulics in the Hydraulics Investigations Section, Hydraulic Data Branch, Division of Water Control Planning.

H. U. Sverdrup of the Norwegian Polar Institute, was awarded the Patron's Medal of the Royal Geographic Society at its Annual Meeting at London, England, in June 1950. He was scheduled to leave Norway in November for a five-month stay in Antarctica with the Joint Norwegian-Swedish-British Antarctic Expedition.

Merle A. Tuve, Director, Department of Terrestrial Magnetism, Carnegie Institution of Washington, has been awarded the Howard A. Potts Medal by Franklin University for his work in developing the radio proximity fuse during World War II.

Ilmari Bonsdorff, former Director of the Geodetic Institute of Finland, died October 17, 1950 at the age of 71.

Frederick William Greve, Professor of Hydraulic Engineering at Purdue University, died January 13, 1950 at the age of 64. He was born in Brooklyn, N. Y. He received his baccalaureate degree from the University of Wisconsin in 1908, worked for the International Pump Co. a short time, and taught at Oregon State College in 1910-1911. He then began his work at Purdue University. During the 1930's, he served on committees concerned with the extensive drainage basin reports of the U. S. Planning Board. He had been a member of AGU since 1945.

Norman E. Hawes, Forester with the Northeastern Forest Experiment Station, Upper Darby, Pa., died April 16, 1950 at the age of 44. He was born in Boston, Mass. and obtained his baccalaureate degree from Washington and Lee University in 1929, and his Master's degree in Forestry from Yale in 1932. He then became a member of the Yale Botanical Expedition to the West Indies, and in 1935 took up duties with the Federal Government, soon entering the Forest Service, which he served until his death on a variety of assignments, bearing chiefly on research in forest influences in stream flow and erosion. He became a member of AGU in 1944.

·Charles Church Slayton, Captain, U. S. Navy, retired, died suddenly on March 5, 1950 at the age of 62 years. He was born at Springfield, Ohio, and graduated from the U. S. Naval Academy. He served in many capacities, but his chief contribution in geophysics were while he was Commanding Officer of the survey vessel, U. S. S. Hannibal, and as Officer in Charge, Division of Chart Construction of the Navy Hydrographic Office. He had been a member of AGU since 1943.

William G. Smiley, Jr., member of the research staff of the Sun Oil Company in Texas, died November 8, 1950 at the age of 44 years. He was born in Houston. He received his baccalaureate degree from Rice Institute in 1927, and his Master of Arts degree from the same chaool in 1929. His chief work was on the interpretation of seismic data relating to complex subsurface structure, especially related to the search for petroleum and gas reserves. He had been a member of AGU since 1947.

SPECIAL ANNOUNCEMENTS

Twenty-Sixth Regional Meeting to be held in Fresno, California, February 9-10, 1951--This meeting, initiated by the Section of Hydrology, is to be held jointly with the Section of Meteorology. Arch R. Addington, Professor of Geology at Fresno State College, has been designated chairman of the committee on the meeting and its arrangements for the Union, and is also heading up the program planning for the Section of Hydrology. A. A. Lothman, Official in Charge of the U. S. Weather Bureau in Fresno has been designated as chairman of the program for the Section of Meteorology, and will serve on the committee on the meeting for the Union. Interested persons should address their correspondence to one of these two persons.

Thirty-Second Annual Meeting, Washington, D. C., April 30-May 2, 1951--Attention is called to the full notice concerning the Thirty-Second Annual Meeting on page 807 of the October issue of the *Transactions*. Note that titles and abstracts of papers for the program should be sent in as soon as possible, and not later than March 5, 1951. Section Secretaries reserve the right to close programs in advance of that date if programs are filled. Complete manuscripts should be forwarded by April 10, 1951, with advice as to whether the paper is also to be considered for publication in the *Transactions*. Communications should be sent to the appropriate Section Secretary, as listed in the October announcement, or to the office of AGU.

Block bookings have been made at several hotels as follows:

Roger Smith Hotel	18th St. and Pennsylvania Ave., N. W.
Raleigh Hotel	12th St. and Pennsylvania Ave., N. W.
Willard Hotel	Pennsylvania Ave. and 14th St., N. W.
Burlington Hotel	1120 Vermont Avenue, N. W.

Make hotel or room reservation early directly with the hotel of your choice. If using block-booked space, be sure to cite the AGU Meeting.

Ninth General Assembly of the International Union of Geodesy and Geophysics--Plans for this meeting, to be held in Brussels, Belgium August 21-September 1, 1951 are taking form, and it is anticipated that the programs will be complete early in 1951. If you plan to prepare a paper for this program, word of this should be sent to the office of AGU without further delay, indicating the Association (corresponding to AGU Section) for which the paper is intended, with advice concerning the availability of the complete paper (this should be in well in advance of the meeting). If you desire to attend as a delegate from the U. S. A., this word should be sent in promptly. To those who plan to attend as delegates from the U. S. A., AGU will forward word concerning the meeting, accommodations, and related matters as such word comes from Belgium. Note that citizens of U. S. A. should get into touch with the AGU (the National Committee of the U. S. A.), and not with the Belgian Organizing Committee. You must, however, make your own arrangements for passage and for accommodations.

Transactions, American Geophysical Union Volume 31, Number 6 December 1950

UNION, SECTION, AND COMMITTEES ACTIVITIES

REPORT OF COMMITTEE ON AUDIT

Fiscal year July 1, 1949 to June 30, 1950

R. H. Weightman, Chairman
A. G. McNish A. Nelson Sayre

Your Committee on Audit has examined the books of the Union for the fiscal year ending June 30, 1950, and finds them in agreement with the statement of the Union's finances supplied by the General Secretary, which is attached hereto.

The cash assets of the Union at the beginning of the year amounted to $10,032.02, of which $8,552.31 was held as cash reserve; $1,359.41 in the Robert E. Horton fund and $120.30 in the Bowie Medal Fund. All three funds are carried in one account at the Riggs National Bank. The Permanent Fund, in reality our Invested Fund, amounted to $2,768.00 and consisted of $2,368 in Series F Bonds (maturity value $3,200) and $400 deposited in the Northwestern Federal Savings and Loan Association.

Receipts for the year from all sources totaled $36,825.89, while expenditures totaled $33,484.02, an increase in liquid funds of $3,341.87. It was found possible to increase the Permanent Fund by additions of $310 in cash and accumulated interest of $14.73 to the Northwestern Federal Savings and Loan Association account for a total of $724.73. The bond investment remained the same.

At the end of the year, the cash assets and investments of the Union were $13,373.89, an increase of $3,341.87; $1,180.91 was held in the Horton Fund, a decrease of $178.50; and $107.90 was held in the William Bowie Medal Fund, a decrease of $12.40. The Permanent or Invested Fund was increased by $324.73 to $3,092.73.

It is of interest to note that total receipts from dues and memberships in 1950 showed an increase of 35 per cent over the preceding year.

The General Secretary has suggested that the Committee might decide to omit some of the auxiliary statements for publication. We have been glad to avail ourselves of this suggestion and have eliminated a few of the auxiliary statements, but we believe that nothing essential has been omitted.

Statement of assets and liabilities as of June 30, 1949

[From 1949 Report, see Trans. v. 30, p. 934, 1949]

Assets			
Cash Reserve	$ 8,552.31		
Robert E. Horton Fund	1,359.41		
William Bowie Medal Fund	120.30	$10,032.02	
Permanent Fund			
Series F bonds purchased prior to July 1, 1948 (maturity value $3,200) at cost	$ 2,368.00		
On deposit in Northwestern Federal Savings and Loan Association	400.00	2,768.00	
			$12,800.02
Bills receivable			4,935.86
			$17,735.88
Liabilities			
Bills payable			$ 337.64
Surplus (capital account)			17,398.24
			$17,735.88

Operating Statement

(Fiscal year ending June 30, 1950)

Receipts			
Grant			
National Research Council			$ 400.00
Income			
Dues 1947-1951 et seq			
1947	$ 32.50		
1948	165.00		
1949	2,864.00		
1950	25,075.00		
1951 et seq	161.30		
Corporation Memberships (three 1949 and two 1950)	500.00	$28,797.80	
Sales, *Transactions*		5,188.89	
Sales, Reprints		2,245.12	
Sales, Maps		10.25	
			$36,242.06
Interest, Northwestern Federal Savings and Loan Association for 1949 and 1950			14.73
Miscellaneous contributions			169.10
			$36,825.89
Disbursements			
Publishing *Transactions*			
Printing	$ 7,917.85		
Preparing manuscript	7,251.29		
Mailing	910.89		$16,080.03
Reprints			1,784.04
General Expenses, Office of Union			
Salaries for services		$10,534.09	
Stationery and supplies		743.62	
Postage and communications		1,144.30	
Office equipment		307.22	12,729.23
Expenses, meetings			
Annual Meeting		$ 587.15	
Regional Meetings		82.07	669.22
Expenses, Sections (Section of Hydrology)			13.24
Expenses, Committees (Membership Committee)			45.12
Honoraria to editors			1,350.00
Travel of officers			100.20
Robert E. Horton papers (paid from Robert E. Horton Fund)			178.50
William Bowie Medal (paid from William Bowie Medal Fund)			12.40
Index of Transactions (first 25 years, 1920-1944)			
Salaries		$ 110.92	
Supplies		8.75	119.67
Miscellaneous			77.64
Investments: deposited in Northwestern Federal Savings and Loan Association as part of Permanent Fund ($240.00, plus check No. 3422 dated June 30, 1950 in favor of the Association for $70.00; plus interest for 1949 and 1950 of $14.73)			324.73
			$33,484.02

Excess of receipts over disbursements

Receipts	$36,825.89	
Disbursements	33,484.02	
Increase in liquid funds (Cash Reserve)		$ 3,341.87

Statement of assets and liabilities as of June 30, 1950

Assets			
Cash Reserve	$12,085.08[a]		
Robert E. Horton Fund	1,180.91		
William Bowie Medal Fund	107.90	$13,373.89[b]	
Permanent Fund			
Series F bonds purchased prior to July 1, 1948 (maturity value $3,200) at cost	2,368.00		
On deposit in Northwestern Federal Savings and Loan Association; $640.00 with accumulated interest of $14.73 and check for $70.00 not yet deposited on June 30, 1950	724.73	3,092.73	
			$16,466.62
Bills receivable			
Publications	575.61		
Dues	6,924.00		7,499.61
			$23,966.23
Liabilities			
Bills payable and advance payments			
National Academy of Sciences (Thirty-First Annual Meeting)	$ 111.27		
Publications and dues paid in advance	429.66		$ 540.93
Surplus (Capital account)			23,425.30
			$23,966.23

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[a] Subject to commitments made in the last fiscal year as follows:
Travel to international meetings, $250; and Directory of members, $500.00

[b] Riggs National Bank statement of June 30, 1950	$16,123.36
Less checks outstanding	2,749.47
Balance June 30, 1950 as above	$13,373.89

Fifth General Assembly of the Pan American Institute of Geography and History--The Fifth General Assembly of the Pan American Institute of Geography and History was held in Santiago, Chile, October 16-27, 1950. AGU was represented by Elliott B. Roberts, Captain, U. S. Coast and Geodetic Survey, who conveyed the greetings and best wishes from AGU. He reports excellent technical sessions, with 20 American and five European countries represented. Twelve international organizations, including UNESCO, sent representatives. Over 200 persons were present as official delegates.

Seventy-Fifth Anniversary Celebration of Brigham Young University--On October 16-17, 1950, Brigham Young University celebrated the Seventy-Fifth Anniversary of its founding. The ceremonies included the dedication of a new two-million dollar Physical Science Building which contains a new seismograph station, a weather observatory, and laboratories and other research facilities for physics, chemistry, and geology. One of the largest crystallographic collections in the West, hitherto inaccessible, is being arranged. AGU was represented by Walter M. Elsasser, Professor of Physics of the University of Utah.

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TRANSACTIONS

AMERICAN GEOPHYSICAL UNION

VOLUME 31 NUMBER 5 PART 2

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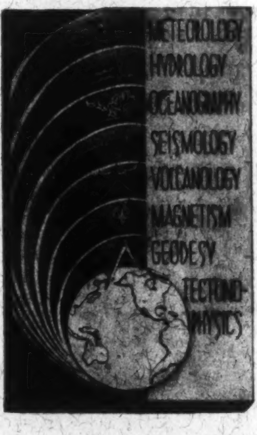
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ALPHABETICAL AND GEOGRAPHICAL LISTS OF MEMBERS

LIST OF COMMITTEES

LIST OF PUBLICATIONS

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AMERICAN GEOPHYSICAL UNION

Established by the National Research Council of the National Academy of Sciences in 1919

To promote the study of problems concerned with the figure and physics of the Earth,
to initiate and coordinate researches which depend upon international and national cooperation,
and to provide for their scientific discussion and publication

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General notice--The American Geophysical Union welcomes papers and discussions on the various geophysical subjects for publication from members and non-members alike. It reserves the right, however, to reject either papers or discussions in whole or in part and in all cases these are edited by the Editorial and Publication Committee. Manuscripts should be transmitted in triplicate to the American Geophysical Union, 1530 P Street, Northwest, Washington 5, D. C., and also proofs and all correspondence concerning papers.

It is the responsibility of each author to prepare his material in logical and attractive form, so that it may be read by a specialist in the particular field without need of interpolating the author's intention. To this end, a circular entitled "Suggestions to authors on preparation of manuscripts for publication in the Transactions of the American Geophysical Union" has been prepared and will be supplied interested persons upon request. Reports and papers should be concise. Historical summaries of previous results and comments that do not lead to definite conclusions should be brief. The amount of detail included should be governed by the importance of the results and of their interest to geophysicists.

The Transactions include several departments, as follows:

(1) Scientific and technical papers
(2) Discussions of papers under (1)
(3) Progress reports
(4) Letters to Editor
(5) Reviews, Abstracts, Bibliography
(6) Notes, Personalia, Corrigenda
(7) Union, Section, and Committee Activities

All matters for (1) should have a definite scientific or technical interest and should develop aspects of the geophysical sciences. Matter for (2) may be submitted for publication within the limiting date set at the close of each paper. Items of temporary interest will ordinarily not appear in (1) but in (3) or (4).

The American Geophysical Union is not responsible for statements made, or conclusions drawn, by contributors.

Return of copy for illustrations--All illustrative material, including any negatives supplied to, or prepared by, the Union, will be returned to authors if request accompanies manuscript; otherwise such copy will be destroyed upon publication of Transactions in which they are printed.

Reprints--Reprints will be furnished at cost to an author provided order is received when corrected proof is returned. When an order is accompanied by remittance in full, reprints will be sent post or express paid; otherwise cost of forwarding will be added to cost of reprints.

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Communications regarding subscriptions, orders, changes of address, and interest in membership should be sent to the American Geophysical Union, 1530 P Street, Northwest, Washington 5, D. C.

PREFACE

In this list of members, the addresses are corrected as received by September 10, 1950. The list supplants that of July 10, 1948, published as Part 2 of the Transactions of August 1948. Following the alphabetical list is a geographical list, by cities and states in the United States and possessions, by cities in Canada where our members are quite numerous, and by countries otherwise. A third portion is a list of the Committees of AGU and its Sections, which in turn is followed by a list of publications of AGU, indicating which are still available.

In the main alphabetical and the geographical lists, the code letters following the names are the usual ones for the Section affiliations, as follows:

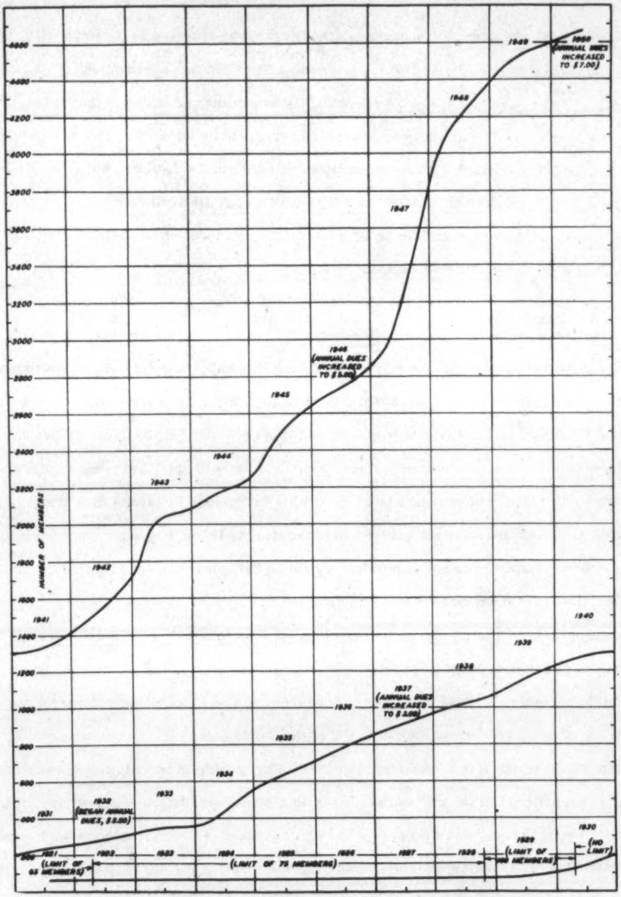
(a) Geodesy
(b) Seismology
(c) Meteorology
(d) Terrestrial Magnetism and Electricity
(e) Oceanography
(f) Volcanology
(g) Hydrology
(h) Tectonophysics

During the War years and immediately following, the importance of Geophysics to our national welfare and to the welfare of the world, has been recognized as never before. The growth of the Union reflects this increased importance, and it augers well for the future of Geophysics and the related professions. Nonetheless, there are still many well-qualified persons who are not now members of AGU, who may now be more readily recognized by members in consulting the geographical listing, the first since 1943. In order that the Union may serve the broadest aspects of Geophysics, as many of these as possible should be brought into membership and, to accomplish this, the aid of the members is solicited.

The geographical listing should also be of use and aid to members who are interested in the development of regional programs of AGU. Such activities must originate with the desire and interest of the members. Those who have such interest will be aided in organizational and planning work by the national officers of the Union and of the Sections.

Geophysicists should feel encouraged by the healthy growth of activity in the various geophysical sciences, not only on the national scene but on a world-wide basis. Internationally, the International Union of Geodesy and Geophysics and its constituent Associations occupy a key position. The Eighth General Assembly in Oslo in 1948, and the forthcoming one in Brussels in 1951, point to a strengthening of a period of international cooperation, coordination, and progress. The development of the Earth Sciences is an important cog in the maintenance and growth of world-wide culture, and the constructive development of the resources of the Earth.

1530 P Street, N. W.,
Washington 5, D. C.,
September 1950



Membership, dates of increase in membership limit, and origin and increase of annual dues, American Geophysical Union, 1921-1950

AMERICAN GEOPHYSICAL UNION

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Lomita--J. C. Alter (cg)

California--Continued

Long Beach--A. A. Garrett (g), W. A. Kelly (dfgh), F. O. Klein (d), C. R. Partridge (b), M. S. Paul (c), D. C. Pontius (cfg)
Los Altos--H. P. Blanchard (d), S. H. Williston (d)
Los Angeles--D. Alter (c), J. C. Arnold (bd), H. P. Bailey (c), D. M. Baker (g), T. B. Barnidge (c), D. Baron (g), P. Baumann (cg), A. D. Belmont (cg), C. A. Bengtson (abcdefgh), J. A. B. Bjerknes (c), H. F. Blaney (g), R. H. Blanford (g), S. Bohrer (bg), M. Bookman (g), E. R Bowen (g), E. C. Bowman (h), M. N. Bramlette (aeg), R. N. Bruyere (abcdefgh), C. E. Burgess (g), M. F. Burke (cg), S. S. Butler (g), C. Cassel (bh), D. E. Cole (cg), H. Conkling (eg), H. Cox (b), J. C. Crowell (cegh), C. J. Derrick (b), C. Durrell (fh), R. Eckis (bg), C. C. Elder (cg), K. O. Emery (de), W. A. English (b), W. H. Geis (b), R. M. Glendinning (cg), M. Glicken (ad), H. R. Gould (efg), B. S. Grant (g), U. S. Grant (eg), D. T. Griggs (abfh), W. I. Hicks (g), R. A. Hill (g), J. Holmboe (c), R. E. Holzer (cd), R. D. Horne (abe), H. W. Hoylman (bdfh), M. R. Huberty (g), J. J. Jakosky (ad), R. B. Jansen (bg), J. G. Jobes (cg), J. Kaplan (cd), W. W. Kellogg (cd), H. C. Kelly (g), E. J. Koch, Jr. (g), W. A. Lang (cg), R. O. La Rue (b), C. T. Leeds (beg), D. J. Leeds (b), R. H. Levine (g), H. B. Lynch (g), R. W. Mathews (g), D. A. McNaughton (g), Y. Mintz (c), S. B. Morris (bcg), M. Neiburger (ce), C. E. Palmer (c), C. T. Pierson (fh), A. F. Pillsbury (g), W. C. Putnam (abcefg), R. E. Rule (bcfgh), W. G. Ryals (bcfgh), H. Salvatori (b), Z. Sekera (ce), L. A. Sergius (eg), N. R. Shade (abcdeh), H. N. Shepard (g), L. Sherman (c), A. K. Showalter (cg), R. R. Simonson (abdgh), L. B. Slichter (abdh), A. L. Sonderegger (eg), G. S. Tapley (g), G. M. Thayer (eg), R. G. Thomas (aegh), H. C. Troxell (gh), K. Q. Volk (bcg), H. C. Whittlesey (b), C. H. Wilson (abd), E. A. Withers (g), D. R. Woodward (g), H. Yarborough (abe)
Los Gatos--G. D. Eberlien (fh)
Madera--H. Barnes (g)
McClellan--C. G. Markham (c)
Menlo Park--S. W. Grinnell (g), A. Locke (fh), W. S. T. Smith (befgh)
Merced--F. I. Bluhm (g), K. R. McSwain (g)
Mill Valley--P. C. Bateman (fh)
Mission Beach--J. Ludwick, Jr. (eg)
Mojave--O. J. Backus (bcg)
Monterey--W. D. Duthie (c)
North Hollywood--M. Anderson (g), C. J. Dommes (g), J. W. Luce (bcfg), J. Paull (abceg), R. W. Rutowski (acg), H. B. Shapiro (cg), I. Sherman (ag), R. Stone (beh)
North Sacramento--G. H. Davis (g)
Novato--W. Q. Wright, Jr. (abcdgh)
Oakland--P. B. Boyer (cg), R. P. Cook (cg), W. T. Czuba (cg), R. O. Eaton (e), J. Hershberger (abdh), D. H. Miller (cg), H. W. Oliver (g), W. Russ (g), G. H. Russell (cg), C. H. Sandberg (adfh), P. D. Trask (ceg), R. L. Wiegel (e)
Orange--D. L. Gardner (g)
Orcutt--J. J. McCullough (d)
Pacific Palisades--G. Tunell (fh), D. E. Whelan, Jr. (ade)
Palo Alto--H. Forbes (g), C. V. Givan (cg), L. M. Henry (c), E. P. Hollis (bdh), D. H. Hutchison (c), G. M. MacLeod (bg), J. W. Rolston (ceg), G. A. Waring (g)
Palos Verdes Estates--R. I. Meeker, Jr. (c)
Pasadena--W. S. Adams (d), J. A. Anderson (b), K. E. Andrews (bcd), S. J. Barnett (d), H. Benioff (bh), E. Bollay (ceg), J. P. Buwalda (beh), I. Campbell (cfgh), T. E. Dennis (b), L. de Witte (bdh), C. H. Dix (abdh), B. H. Dodge (g), D. E. Flint (fh), A. J. Grobecker (bh), B. Gutenberg (abcdefgh), D. F. Hewett (fg), H. Hoover, Jr. (abcdefgh), R. A. Hoppin (cefh), G. W. Housner (b), E. Hsu (g), C. R. Huffman (f), M. C. Israelsky (eg), R. H. Jahns (fgh), H. F. Jerauld (g), J. J. Johnson (bd), R. T. Knapp (ceg), F. B. Laverty (cg), A. W. Lyons (h), C. W. Merriam (h), R. A. Millikan (cd), B. T. Morris (g), L. K. Morris (ab), J. M. Nordquist (abcfh), J. T. O'Brien (eg), G. W. Potapenko (ad), A. B. Poynter (bd), W. H. Rempel (c), C. F. Richter (bh), F. E. Roach (d), R. P. Sharp (fg), E. L. Smith (g), J. L. Soske (bcdfh), N. C. Stone (c), H. E. Thalmann (e), F. Thomas (g), H. R. Thornburgh (abcefh), V. A. Vanoni (g), K. Venkateswarlu (abcdefgh), T. von Karman (ceg), W. O. Wagner (ag), O. J. Wittman (g), H. O. Wood (abfh), O. R. Wulf (cd), F. Zwicky (dgh)
Paso Robles--J. W. Higgins (afgh)
Piedmont--O. W. Swainson (bde)
Pomona--V. S. Aronovici (cg), R. B. McRae (b), D. C. Muckel (g), J. O. Reeve (g)
Porterville--I. H. Althouse (g)
Port Hueneme--W. A. Bowen, Jr. (d)
Redding--J. P. Albers (f)
Redlands--S. W. Dana (bdh), B. Dibble (g), H. P. Hinckley (g), G. I. Lang (g), J. J. Prendergast (g)
Redondo Beach--M. C. Chittenden (b), J. B. Petrie (e)
Redwood City--W. T. Wilson (cg)

California--Continued

Rialto--M. B. Scott (g)
Richmond--C. L. Bretschneider (c)
Riverside--M. Donnelly (cg), J. L. Merriam (cg), L. A. Richards (cgh), S. J. Richards (g), L. V. Wilcox (g)
Sacramento--H. O. Banks (gh), R. T. Bean (g), G. B. Blackstone (cg), M. H. Blote (g), L. E. Bossen (g), J. S. Cotton (cgh), W. I. Gardner (fg), A. Givan (cg), A. Gomez (g), C. O. Greenwood, Jr. (abcdefgh), J. W. Gross (cg), J. M. Haley (g), J. B. Hammon (ag), V. J. Hansen (cg), G. H. Hargreaves (g), C. H. Harned (bfgh), L. K. Hill (cgh), C. P. Holdredge (befg), W. H. Holmes (ad), L. K. Homer (g), E. Hyatt (abcdh), R. P. Ireland (g), B. L. Johnson (g), C. H. Kromer (bfh), J. W. Kuhnel (g), L. H. Magar (aceg), E. C. Marliave (g), J. Osoffsky (g), W. H. Parrott (ce), J. B. Paulsen, Jr. (cg), G. A. Peers (g), J. F. Poland (gh), E. P. Price (cdg), P. Reiche (fgh), R. R. Rowe (cg), V. W. Rupp (g), A. W. Schimberg (bgh), C. E. Schneider (g), W. G. Schulz (g), H. M. Stafford (g), D. S. Stoner (g), E. F. Sullivan (g), A. C. Swanson (g), R. O. Thomas (cg), H. G. Thomasson, Jr. (cg), R. C. Treasher (bfg), J. E. Upson (g), C. P. Van Camp (a), E. P. Warren (g), G. F. Worts, Jr. (g)
San Bernardino--L. Martin (cg), A. F. Moore (bcdg), J. Oliver (g), W. P. Rowe (g), R. V. Ward (g)
San Bruno--E. M. Vernon (c)
San Diego--E. R. Anderson (ce), A. L. Brosio (cg), M. E. Brown (a), E. C. Buffington (aefgh), A. J. Carsola (efh), R. S. Dietz (e), J. D. Frautschy (aeg), L. E. Garrison (e), H. P. Gates (d), R. S. Holmgren (ag), E. C. LaFond (c), R. M. Lesser (ce), J. J. Marciano (ceg), C. R. Moe (de), V. G. Plank (c), R. D. Russell (abcdefgh), J. F. Theodore Saur, Jr. (ce), T. Saville, Jr. (e), D. A. Wilson (e), J. F. Wingo (g)
San Fernando--K. F. Chang (cg)
San Francisco--F. M. Anderson (c), C. V. Averill (f), Louise A. Boyd (ceg), R. C. Briggs (g), Marguerite Butler (c), R. S. Chew (b), L. D. Clark (d), W. K. Cloud (bdg), E. H. Cobb (f), W. S. Dawson (cd), H. H. Engelbrecht (g), E. L. Felton (c), D. B. Freeman (g), J. F. Gaillard (c), M. A. Garbell (cde), G. O. Gates (abcdefgh), R. Y. Grant (fg), H. Green (bfg), R. R. Griswold (g), C. F. Hains (g), G. T. Hirashima (cg), S. R. Hoffman (bcdfgh), W. L. Huber (g), L. H. Hutchinson (c), T. D. Irvine (g), M. V. Jiranek (cg), W. S. W. Kew (beh), H. Kramer (g), C. H. Lee (g), J. H. Lensch (g), J. F. McAllister (f), D. H. McLaughlin (efgh), A. J. Meadowcroft (g), T. H. Means (bcg), A. I. Mei (b), F. A. Menken (abcdefgh), R. C. Miller (ceg), A. L. Morris (cg), S. K. Neuschel (efg), C. T. Newton (g), A. H. Nicol (fgh), G. B. Oakeshott (f), H. M. Orem (cg), B. M. Page (bfgh), C. Pierce (ae), J. S. Shapland (g), L. W. Stach (abeh), W. Stava (cg), I. H. Steinberg (g), J. A. Stirton (ae), F. P. Ulrich (bd), F. A. Wade (fgh), R. A. Wells (cg), W. S. Weyant (c)
San Gabriel--W. E. Bergh (g)
San Jose--E. F. Ryan (cd), E. E. Stohsner (ab)
San Leandro--G. E. Daniels (cg), S. E. Rantz (g), H. E. Root (cg)
San Lorenzo Village--W. A. Waldorf (bcg)
San Marino--C. H. Johnson (abdfh), F. S. Parker (bdh), R. W. Spencer (agh), V. W. Vandiver (beh)
San Mateo--L. D. Doty (cg)
San Rafael--C. J. Leith (fh)
Santa Ana--A. H. Holland (g), R. Sturdevant (bfh), M. N. Thompson (cg)
Santa Barbara--H. D. Wilson, Jr. (g), D. M. Wootton (eg)
Santa Clara--J. A. Weber (bc)
Santa Monica--N. E. Edlefsen (cgh), F. H. Kranz (c)
Santa Paula--V. M. Freeman (g)
Sierra Madre--J. H. Carr (eg)
Soda Springs--C. W. Mansfield (cg)
South Laguna--W. Ayvazoglou (d)
South Pasadena--T. H. Braun (b), R. C. Osburn (aegh), A. F. Woodward (bef)
Stanford--J. B. Franzini (acg), E. L. Grant (g), R. A. Helliwell (d), A. D. Howard (efg), E. G. Johnsen (g), K. B. Krauskopf (fh), A. I. Levorsen (abgh), R. K. Linsley, Jr. (g), L. A. Manning (cd), S. W. Muller (gh), C. R. Murray (g), T. C. Poulter (abd), C. M. Swinney (fh), J. K. Vennard (g), A. C. Waters (bfh), D. Whitaker (ex officio)
Stockton--V. W. Barth (g), G. E. Fowler (abcfgh), W. J. Miller (befh), C. A. Morelli, II (abcfgh), M. E. Murphy (g)
Susanville--W. A. Biehler (g)
Taft--L. F. Ivanhoe, Jr. (abdfgh), N. J. Lea (b), A. Paap (bfh)
Temple City--P. St. Amand (abdh)
Vallejo--A. H. Baldwin (b)
Van Nuys--J. C. Fredericks (g), E. R. Orwig, Jr. (abefgh), J. E. Slosson (eg)
Ventura--T. L. Bailey (abefh), R. H. Jamison (g)
Walnut Creek--J. W. Mixsell (cg), R. D. Tarble (cg)

Whittier--M. L. Hill (h), W. J. Wood (cg)
Yreka--G. R. B. Elliot (dfh)
Yucaipa--W. D. Gerke (g)

Canal Zone

Balboa--W. A. Shreve (c)
Cristobal--H. W. Bigelow, Jr. (aeg)

Colorado

Arvada--C. O. Hurd (b)
Aurora--W. D. Dickey (c), S. E. Hook (c)
Boulder--J. W. Broxon (d), B. J. Chronic, Jr.,(abcdefgh), L. F. Kengle, Jr. (e), Julie A. Klovstad (dh), O. C. Jester, Sr. (cd), J. W. Marr (cg), E. E. Wahlstrom (fh)
Brush--N. M. MacNeill (g)
Denver--T. P. Ahrens (cfgh), H. A. Aurand (cd), J. H. Baily (g), A. C. Barlow (g), F. M. Bell (g), G. C. Bennet (ceg), W. E. Benson (ceg), F. A. Bertle (g), A. W. Black (b), Margaret F. Boos (fh), W. M. Borland (acg), L. H. Boyd (ab), F. M. Byers, Jr. (f), B. F. Curtis (cgh), D. W. Davis (g), C. E. Dobbin (befh), G. R. Downs (bf), E. B. Eckel (fg), J. Fishback (g), P. M. Ford (cg), E. E. Foster (cg), W. U. Garstka (cg), J. Gilluly (abefgh), H. P. Grout (cg), O. C. Hansen (g), H. E. Hawkes, Jr. (dfh), C. A. Heiland (abdh), P. V. Hodges (g), J. C. Hollister (b), I. E. Houk (bcg), L. C. Huff (g), C. B. Hunt (fh), W. H. Irwin (fgh), R. A. Jachowski (abefgh), R. E. Kennedy (cg), G. J. Kindel (c), V. A. Koelzer (cg), E. W. Lane (ceg), H. Larson (cg), F. Lewis (ceg), S. W. Lohman (g), C. R. Maierhofer (ag), J. H. Maxson (bfh), A. W. McCow, III (bfh), T. G. McLaughlin (fgh), J. S. Meyers (cg), S. A. Miller (g), W. C. Northcutt (b), L. R. Page (f), E. L. Pemberton (g), H. L. Potts (g), W. J. Powell (g), H A. Powers (f), K. Ramachandran (g), R. Rhoades (fgh), H. S. Riesbol (cg), G. D. Robinson (bfh), E. Rose (bcg), G. Rouse (bh), J. I. Sanders (g), L. M. Seavy (g), J. F. Smith, Jr. (efgh), K. Stefansson (h), L. W. Storm (abcde), H. L. Thomsen (ab), R. J. Tipton (cg), O. L. Tweto (fh), C. M. Umar (g), D. J. Varnes (fh), D. C. Wellman (bh), H. P. Wheeler (cg), R. D. White (gh), R. E. Wilcox (dfg), J. R. Winnek (b), J. J. Wright (beg)
Durango--W. H. Austin, Jr. (abeh), K. M. Willson (abcdefgh)
Fort Collins--M. L. Albertson (cg), E. G. Dunford (g), D. V. Harris (fgh), L. D. Love (g), R. L. Parshall (g), D. F. Peterson, Jr. (acg), C. Rohwer (g), E. F. Schulz (cg)
Fort Morgan--L. J. Bjorklund (g)
Golden--D. F. Coolbaugh (abdh), R. C. Holmer (bd), R. J. Hughes, Jr. (abcdefgh), C. W. Livingston (h), P. A. Rodgers (d), J. W. Vanderwilt (fh), F. M. Van Tuyl (abcdefgh), W. R. Wagner (fh), R. A. Wise (b)
Grand Junction--L. C. Craig (afgh), N. H. Daines (g), D. Gallagher (afh), R. D. Goodrich (g), C. N. Holmes (g), D. A. Phoenix (g)
Gunnison--H. K. Rouse (g)
Holyoke--E. O. McCutchen (abdeh)
Lafayette--F. E. Moore (fh)
Lakewood--B. S. Barnes (cg), D. G. Wyant (dfh)
Las Animas--L. Fischer (abcfh)
Limon--W. C. Spicer (abd)
Meeker--J. P. Baughman (ab)
Mesa Verde National Park--R. H. Rose (bcfg)
Pueblo--J. W. Gabelman (fh)
Uravan--F. W. Cater, Jr. (fh)
Wheatridge--R. P. Leatham (ceg)

Connecticut

Bridgeport--F. L. Panuzio (acgh)
Canaan--W. D. Lambert (abeh)
Glastonbury--R. E. Huschke (c)
Groton--H. von Schelling (cg)
Hartford--C. M. Saville (cg)
Middletown--R. V. Cushman (fgh), N. Herz (fh), J. W. Peoples (fh)
New Canaan--E. H. Boissonnas (bd)
New Haven--A. M. Bateman (acfg), G. Breit (d), D. Brouwer (a), C. O. Dunbar (c), R. F. Flint (ceg), A. Knopf (fh), Eleanora B. Knopf (fh), C. R. Longwell (abefh), H. J. Lutz (g), J. Rodgers (fh), C. L. W. Swanson (cg), M. S. Walton, Jr. (bdefh), H. Winchell (fgh)

Connecticut--Concluded

New London--C. T. Berry (bef), J. M. Ide (b), W. C. Sands (e)
Norwalk--C. K. Panish (acegh)
Ridgefield--H. G. Doll (d)
Storrs--Janet M. Aitken (fh), J. B. Lucke (beh), K. C. Tippy (acgh), A. N. Vanderlip (ag)
West Hartford--B. L. Bigwood (g)

Delaware

Wilmington--J. L. Gillson (fg), C. A. Gosline (c), W. J. Sloan (g)

District of Columbia

Washington--C. G. Abbot (c), S. Abrahamson (c), Bernice Ackerman (ceg), L. H. Adams (bdfh), L. B. Aldrich (cd), Alice S. Allen (bdgh), C. T. Allen (a), Louis P. Allen (cdeg), A. D. Anderson (c), J. B. Anderson (c), M. J. Andre (c), D. A. Andrews (fh), J. F. Andrews (c), H. Arctowski (cefh), C. I. Aslakson (abcde), E. J. Aubert (c), T. S. Austin (e), J. H. Baden, Jr. (bcd), L. F. Bailey (b), A. A. Baker (fgh), J. R. Balsley, Jr. (h), J. M. Barry (acdgh), C. C. Bates (bce), L. J. Battan (c), C. M. Bauer (ag), H. Bay (a), K. H. Beij (g), M. A. Benson (cg), Jean M. Berdan (g), M. Bernard (cg), F. A. Berry, Jr. (c), P. K. Bhattacharya (bcd), C. Bittinger (be), R. F. Black (gh), A. J. Bodenlos (fh), R. R. Bodle (bh), L. D. Bonham (h), K. S. Bonwit (b), J. C. Bose (ae), N. L. Bowen (bfh), N. F. Braaten (a), W. H. Bradley (efh), M. Brenner (abcdefgh), L. J. Briggs (aef), J. H. Brittain (ae), D. L. Brooks (a), L. E. Brotzman (ceg), E. B. Brown (ade), G. F. Brown (fg), R. H. Brown (g), C. D. Bue (cg), R. C. Bundgaard (c), P. B. Bunton (abcdefgh), W. S. Burbank (fh), N. M. Burgner (c), T. L. Burkett (c), J. S. Burlew (fh), C. A. Burmister (abde), E. B. Burwell, Jr. (bfgh), J. M. Caldwell (eg), C. J. Callahan (c), J. A. C. Callan (g), D. S. Carder (bdfh), J. Carroll (a), W. B. Chadwick (acdh), W. C. Chamberlin (ah), F. Chayes (fh), C. Chow (a), A. H. Clark (e), R. R. Coats (fh), W. A. Cobban (e), L. O. Colbert (abde), L. A. Cole (e), W. D. Collins (g), H. L. Cook (bcg), M. M. Cook (ae), H. J. Coolidge (abcdefgh), J. R. Cooper (abfh), J. A. Copeland (c), J. H. Cornish (ceg), A. Court (cg), D. B. Cowie (d), R. W. Craig (c), S. C. Craigie (a), F. L. Culley (a), R. N. Culnan (ceg), T. Dalrymple (cg), H. H. Darby (e), R. W. Davenport (g), G. L. Davis (fh), R. M. Davis, Jr. (d), W. S. Davis (ac), E. A. Deily (abde), W. J. Dempsey (d), L. P. Disney (e), P. C. Doran (abde), J. V. N. Dorr, II (fh), H. G. Dorsey (e), C. A. Douglas (c), J. H. Douma (cg), E. G. Droessler (c), H. W. Dubach (c), J. A. Duerksen (a), D. C. Duncan (f), H. N. Eaton (eg), H. R. Edmonston (e), C. R. Elford (cdeg), C. F. Ellingwood (a), W. D. Ellison (g), W. D. Ellison, Jr. (d), G. A. Engen (ae), J. L. England (fh), A. V. English (a), G. H. Espenshade (fh), P. B. Everson (ae), F. S. Farquhar (e), G. E. Ferguson (g), A. G. Fiedler (g), R. B. Finley (a), Doris J. Finney (a), G. FitzGerald (a), J. A. Fleming (bcdeh), R. H. Fleming (e), R. D. Fletcher (ceg), G. M. Flint, Jr. (ag), F. J. Flynn (cg), S. E. Forbush (dh), W. F. Foshag (f), G. A. Gamow (adh), C. L. Garner (abde), T. N. Gautier, Jr. (d), R. E. Gebhardt (bdc), V. D. George (a), W. D. George (a), R. C. Gibbs (ex-officio), W. M. Gibson (abde), Jewell J. Glass (f), M. I. Goldman (eh), F. R. Gossett (ae), F. R. Gracely (cd), J. W. Graham (bfh), C. K. Green (abde), J. W. Greig (bf), N. C. Grover (g), P. W. Guild (fh), R. Gunn (cdfh), O. E. Guthe (cg), G. A. Guy, Jr. (c), W. F. Guyton (g), F. J. Haight (e), J. V. Hall, Jr. (eg), D. S. Handwerker (a), J. B. Hanley (fh), L. P. Harrison (c), J. C. Harrold (g), W. W. Hastings (g), J. H. Hawley (e), B. C. Haynes (ceg), N. H. Heck (abdeh), J. F. Hellweg (abcd), W. R. Helm (a), H. W. Hemple (ae), L. G. Henbest (e), R. G. Henderson (ad), W. C. Hendrix (de), A. V. Heyl, Jr. (ad), W. E. Hiatt (cg), Anna M. Hietanen-Makela (fh), D. W. Hofer (a), C. W. Hoffer (abh), D. M. Hopkins (f), A. J. Hoskinson (ah), J. Hughes (e), E. O. Hulburt (de), Blanche B. Hull (c), M. N. Hunter (c), L. Hurwitz (abd), E. Ingerson (fh), H. Insley (fh), C. F. Izzard (g), Marion C. Jaster (g), W. A. Jenner (cg), H. R. Joesting (dfh), W. D. Johnston, Jr. (fh), B. E. Jones (bdg), J. W. Joyce (bdh), L. V. Judson (ab), H. P. Kaufman (a), E. N. Kavanagh (g), H. W. Keith, Jr. (abe), F. Keller, Jr. (abcdfh), G. H. Keulegan (g), E. H. Kincaid (cdeh), J. B. Kincer (c), Elizabeth King (bdh), E. Klein (b), D. G. Knapp (d), J. A. Knauss (e), D. W. Knoll (ceg), A. S. Knox (abcdefgh), F. C. Kracek (f), R. F. Kresge (cg), D. B. Krimgold (g), H. S. Ladd (ef), W. B. Lang (egh), W. B. Langbein (abcdefgh), E. S. Larsen, III (f), Esther O. Larson (a), Linnea G. Lauré (a), P. F. LaValle (acg), G. Leifson (ae), E. A. LeLacheur (ceg), L. B. Leopold (g), J. M. LeRoy (cde), M. R. Lewis (g), W. Lewis (c), J. Virginia Lincoln (d), U. J. Linehan (c), R. J. List (c), F. B. Littell (a), D. M. Little (c), K. E. Lohman (g), S. K. Love (g), H. W. Lull (g), A. C. Lundahl (ae), J. P. Lushene (aeh), P. A. Lutz (abcdefgh), J. Lyman (e), W. Malkin (c), G. E. Manger (aefgh), N. E. Manos (ceg), J. P. Marble (f), R. A. Marble (d), H. Marcus (bh), C. G. Mares (abh), H. A. Marmer (eg), J. M. Martin (b), L. Martin (bg), A. H. Mason (ag), J. P. Matarrese (d), J. C. Mathisson (e), R. H. Maynard (bcde), F. W. McBryde (cf), H. E. McComb (bdh), C. E. McCombs (a), C. L. McGuinness (g)

District of Columbia--Concluded

Washington (concluded)--E. C. McKay (ae), V. E. McKelvey (degh), E. T. McKnight (f), M. C. McLean (e), C. H. McLendon (a), B. K. Meade (a), C. D. Meaney (ae), G. Medina (ae), E. L. Merritt (ah), J. B. Mertie, Jr.(abfh), H. E. Merwin (ef), J. L. Meuschke (d), H. A. Meyerhoff (bfgh), R. L. Miller (gh), D. L. Mills (a), N. P. Miloglav (c), C. Milton (f), C. L. Mitchell (c), G. S. Mitchell (c), H. C. Mitchell (a), G. W. Moon (a), H. R. Morgan (a), G. E. Morris, Jr. (ae), F. R. Moulton (ab), R. M. Moxham (a), E. N. Munns (cg), L. M. Murphy (bcfh), J. Namias (c), P. F. Narten, II (g), F. Natella (ae), P. F. Nemenyi (cefgh), F. Neumann (abd), O. Njus (c), T. B. Nolan (fh), S. O'Deorain (g), J. E. O'Hare (ce), B. E. Olson (ce), J. C. Olson (fh), H. Orlin (a), H. T. Orville (c), M. F. M. Osborne (g), W. C. Overstreet (fh), B. L. Page (a), G. G. Parker (cefg), E. J. Parkin (ac), E. H. Patterson (c), J. L. H. Paulhus (c), C. G. Paulsen (g), D. T. Perkins (c), B. J. Peterson (g), T. L. Pewe (cg), G. Phair (fh), J. O. Phillips (abde), Inna V. Poire (fh), A. C. Poling (a), J. Pomerantz (bceh), W. D. Potter (g), F. B. Quinn (ae), J. C. Rabbitt (f), Mary C. Rabbitt (bfh), C. E. Ramser (g), R. H. Randall (ae), H. S. Rappleye (a), L. L. Ray, Jr. (cg), O. S. Reading (ae), C. R. Reed (ae), J. C. Reed (f), F. W. Reichelderfer (c), J. A. Reinemund (bh), J. T. Remick (c), Rosemary E. Riordan (a), O. F. Ritzmann (bdh), E. B. Roberts (abde), R. J. Roberts (f), J. F. Ropek (c), C. S. Ross (f), W. W. Rubey (fgh), Lynn H. Rumbaugh (bdeh), K. P. Ryzhkov (ceg), J. D. Sartor (c), A. N. Sayre (g), W. M. Scaife (abde), J. F. Schairer (f), P. L. Schereschewsky (cd), E. Schmid (a), W. L. Schmitt (e), Dorothy Schneider (e), C. A. Schoene (a), E. O. Schonstedt (d), P. Schureman (e), W. E. Scott (d), H. J. Seaborg (ae), W. O. Senter (c), C. K. Shafer (c), A. L. Shalowitz (e), A. H. Shapley (bdh), B. T. Shaw (g), G. R. Shelton (a), E. R. Shepard (bh), B. J. Sherry (c), A. J. Shneiderov (bd), W. Shofnos (ae), Edna L. Shultz (d), Maria L. Siegrist (afh), L. G. Simmons (a), V. L. Skitsky (ad), T. S. Skowron (a), J. B. Small (a), J. W. Smith (bde), M. B. Smith (d), W. E. Smith (abcdefgh), T. L. K. Smull (c), F. W. Sohon (b), P. Sollenberger (a), A. D. Sollins (a), J. L. Southworth (g), J. L. Speert (ag), R. E. Spencer (cg), H. C. Spicer (bdfh), Taisia M. Stadnichenko (fh), J. L. Stearn (a), J. G. Steele (g), W. F. Steiner (d), R. E. Stevens (bfh), J. W. Steverson (c), R. D. Stowell (c), V. T. Stringfield (g), R. F. A. Studds (abcdefgh), W. D. Sutcliffe (ah), L. W. Swanson (ae), J. S. Sweet (g), B. Swenson (cg), D. M. Swingle (cd), R. B. Sykes, Jr. (ce), C. Symns, Jr. (a), I. R. Tannehill (ceg), H. Tatel (abcdefh), Eloise W. Taylor (d), G. F. Taylor (c), D. Thaler (ce), T. P. Thayer (fh), H. E. Thomas (g), E. S. Thompson (cg), J. C. Thompson (ce), A. C. Thorson (abcde), J. C. Tison, Jr. (a), O. W. Torreson (d), R. Tousey (cd), J. I. Tracey, Jr. (ch), L. B. Tuckerman (dh), M. A. Tuve (d), R. J. Urick (be), J. van de Erve (cg), Florence W. van Straten (c), T. W. Vaughan (acefgh), J. Vederman (c), E. H. Vestine (bcdh), A. O. Waananen (g), A. C. Wagner (ch), G. R. Wait (cdh), C. B. Watts (a), R. H. Weightman (c), F. G. Wells (fgh), H. W. Wells (cd), J. V. B. Wells (g), F. Wenner (bde), M. E. Wennermark (a), L. K. Wenzel (g), W. S. West (acdefg), F. C. Whitmore, Jr. (ae), C. A. Whitten (a), B. W. Wilcox (e), W. E. Wiles (bd), A. H. Williams (g), H. M. Williams (cg), M. G. Williams, Jr. (e), P. H. Williamson (abd), J. W. Winchester (c), K. J. Winiarski (cg), Martha A. Winn (e), E. W. Woolard (c), W. E. Wrather (acefg), F. E. Wright (abfh), D. N. Yates (ceg), H. S. Yoder, Jr. (cef), Olga E. Youngdahl (d), W. B. Zerbe (e), S. Zerfoss (ah), E. G. Zies (ef)

Florida

Belle Glade--H. C. Fears (c)
Cocoa--L. L. Behrendt (c)
Coral Gables--F. G. W. Smith (e)
Daytona Beach--C. W. Parker (c)
Fernandina--G. W. Lovesee (a)
Fort Lauderdale--J. C. Stephens (g), H. T. Stetson (abcdeh)
Gainesville--D. C. Bunting (eg), C. G. Edson (cg), M. W. Jones (bcdh), E. D. Kennedy (cd), H. T. Odum (ce), W. H. Pierson (c), C. Rappenecker (g)
Hialeah--M. W. Edelstein (c)
Jacksonville--E. W. Eden, Jr. (g)
Miami--J. H. Broen, Jr. (c), R. S. Bush (c), E. T. Harding (c), N. D. Hoy (g), J. W. Stewart (g), J. Q. Tierney (e)
Miami Springs--R. F. Clarke (c),
Ocala--C. W. Lingham (g), C. C. Yonker (g)
Opa Locka--M. H. Gilmore (bdh)
Orlando--W. H. Twenhofel (abe)
Panama City--S. Gacesa (c), K. L. Sherman (cdh)
Plant City--J. B. Cathcart, Jr. (ef)
Tallahassee--W. A. Baum (ceg), J. S. Beazley (a), H. H. Cooper, Jr. (g), T. A. Gleeson (c), H. Gunter (adeg), A. G. Matthews (eg)
Tampa--W. W. Sadler (cg)

Georgia

Americus--J. L. Ferguson (c)
Atlanta--R. W. Carter (cg), J. A. Cummings (ce), A. S. Furcron (efg), J. J. George (c), B. M. Hall, Jr. (cg), E. S. Harrison (cg), C. E. Kindsvater (cg), C. P. Lindner (g), R. M. McCarter (c), A. T. Navarre (cf), T. R. Reed (c), C. M. Thomas (abe), M. T. Thomson (g)
Augusta--H. Raynes (cg)
Cairo--P. W. Schinkel (a)
Cartersville--T. L. Kesler (fh)
Dillard--E. A. Johnson (ag)
Emory University--J. G. Lester (fh), A. C. Munyan (abcdefgh)
Forest Park--L. P. Gibbon (a)
Hapeville--D. W. Miller (c)
Macon--W. H. Miller (c)
Savannah--F. J. Rawstrom (g), H. Sugden (aeg), C. F. Trainor (g)
Valdosta--G. A. Clark (cg)

Guam

Guam--J. L. Beatty (gh)

Hawaii

Eleele, Kauai--R. H. Cox (g)
Ewa, Oahu--L. R. Burgess (abcd), R. F. White (bd)
Haiku, Maui--R. N. Thomas (g)
Hawaii National Park--R. H. Finch (bf), G. A. Macdonald (bfh)
Hilo--E. L. Bartz (g)
Honolulu--L. D. Baver (g), R. C. Becker (cdg), H. W. Brodie (c), M. H. Carson (g), R. K. Chun (abg), D. C. Cox (fgh), J. B. Cox (g), D. A. Davis (gh), W. H. Eller (bdfh), T. A. Jaggar (abefh), R. H. Monroe (g), W. A. Mordy (c), W. P. Nash (c), H. S. Palmer (bfg), M. B. Schaefer (e), R. H. Simpson (c), C. K. Stidd (c), H. A. Wadsworth (g), C. K. Wentworth (eg), E. A. Wilder (cg)
Lanai City--J. C. Medcalf (ceg)
Lihue, Kauai--T. T. Brown (de)

Idaho

Boise--W. D. Criddle (cg), D. E. Donley (cg), R. W. Gay (g), H. D. Hafterson (cg), M. R. Kulp (g), R. L. Nace (gh), T. R. Newell (g), C. J. Okeson (af), R. W. Revell (g), L. R. Swarner (g)
Bonners Ferry--H. J. Critchfield (abcdefgh), T. O. Miller (g),
Idaho City--H. F. Haupt (cg)
Idaho Falls--H. C. Eagle (g), P. A. Humphrey (c)
Moscow--C. C. Lomax, Jr. (acg), V. E. Scheid (fh), C. C. Warnick (g), W. L. Youngquist (egh)
Pocatello--G. L. Bell (fgh), D. W. Brown (bdf), A. Isotoff (f)
Priest River--J. D. McWethy (c)
Rathdrum--J. C. Beebe (g)
Wallace--F. M. Galbraith (abd)

Illinois

Aurora--A. Blake (bdeh)
Barrington--J. C. Bellamy (c)
Bartonville--L. Gwaltney (c)
Belleville--J. P. Hereford (c), R. G. Mann (cg)
Cairo--J. F. McGruder(cg)
Carbondale--S. E. Harris, Jr. (eg)
Centralia--J. L. Lester (abcdefgh)
Chanute AFB--C. H. Helman, Jr. (c)
Champaign--W. S. Daniels (g), R. G. Godfrey (cg), C. D. Martin (c), W. D. Mitchell (g), J. H. Morgan (g), E. H. Muller (cfg), W. J. Roberts (cg), F. Sargent, II (c)
Chicago--J. Badner (c), R. Balk (fh), E. W. Barrett (c), E. F. Bourne, Jr. (c), J. C. Boyce (d), R. R. Braham, Jr. (c), J. Harlen Bretz (g), H. R. Byers (ceg), H. D. Dyck (c), F. W. Edwards (g), D. J. Fisher (fh), D. Fultz (c), S. D. Ginsberg (acg), L. Horberg (gh), Y. Hsieh (abcdefgh), V. E. Jakl (c), A. A. Kalinske (g), L. D. Kaplan (cdeg), H. S. Kenny (c), D. S. H. Louie (g), Joanne S. Malkus (ce), E. H. Martin (c), L. L. Means (abcdefgh), H. Moses (c), R. T. Nelson(c),

Illinois--Concluded

Chicago (concluded)--W. H. Newhouse (f), Margaret T. Newman (ce), C. W. Newton (c), R. W. Nicholson (c), M. J. Olascoaga (ac), W. F. Petersen (c), F. J. Pettijohn (egh), R. S. Platt (c), G. W. Platzman (ceg), H. Ramberg (fh), K. Rankama (eh), H. Riehl (c), F. C. Roop (cg), W. J. Saucier (c), A. R. Schmitt (b), J. R. Stair (cg), F. W. Trezise (cdeg), H. A. Wadell (eg), T. Wasson (abdg), R. Wright (fh), R. E. Wright (c), A. F. Zavist (cf)
De Kalb--L. T. Caldwell (abcdefgh)
DeLand--J. L. Hubbard (c)
East St. Louis--N. C. Beck (c)
Effingham--H. H. Luttrell (bf)
Evanston--E. E. Bergman (dh), J. B. Cullison, Jr. (c), E. C. Dapples (eg), R. M. Garrels (h), H. P. Hall (bgh), W. S. Hamilton (cg), A. L. Howland (f), W. C. Krumbein (ceg), P. C. Rutledge (g), L. L. Sloss (eh), J. T. Stark (befh)
Kinmundy--R. D. Mahan (cg)
La Grange--G. E. Dunn (ce)
Manito--C. E. Van Orstrand (abfh)
Moline--L. A. Carlson (g), C. F. Giffey (cg), B. H. Ter Maath (acgh)
Mt. Vernon--J. Neely (ab)
Oak Park--L. K. Sherman (cg)
Olney--R. Hamblin (b)
Orland Park--Karin M. Gleim (ceg)
Paxton--H. W. Schwartz (c)
Rantoul--J. S. Restivo (cefgh), G. C. Scribner (ceg)
Rock Island--A. F. Burleigh (cg), F. M. Fryxell (g), J. O. Letts (g)
Salem--B. A. Barnes (g)
Sidney--J. Everitt (be)
Springfield--W. J. Andrews (g), J. S. Bell (g), R. O. Fisher (g)
Tuscola--H. E. Romine (g)
Urbana--R. Adams (ex-officio), C. A. Bays (bg), A. H. Bell (dh), A. Bevan (bgh), W. F. Bradley (fh), M. B. Buhle (dg), V. T. Chow (g), G. H. Dell (a), J. J. Doland (g), W. D. Gerber (cg), R. E. Grim (bdefgh), J. C. Guillou (g), A. F. Hagner (f), J. F. Halsey (g), J. L. Hough (egh), F. A. Huff (c), J. W. Lawrence (g), K. J. Li (g), W. F. Lytle (cg), J. F. Mann, Jr. (cefg), K. S. Pister (g), M. W. Pullen, Jr. (dh), M. O. Schmidt (ah), R. F. Scott (ceg), P. R. Shaffer (g), J. A. Simon (fg), H. F. Smith (g), G. E. Stout (cg), M. Suter (g), Enid Townley (bcd), C. A. Van Doren (cg), H. R. Wanless (bcefgh), G. W. White (g), H. B. Willman (g)

Indiana

Bloomington--R. E. Cleland (ex-officio), R. L. Ives (cg), B. H. Mason (efgh), J. Mead (bd), P. D. Proctor (g), S. S. Visher (cg), C. J. Vitaliano (f)
Collegeville--J. H. Dante (abeg)
Corydon--G. Campbell (ag)
Evansville--K. G. Boling (ab), M. Rogers (bf)
Greencastle--C. L. Bieber (bc)
Indianapolis--G. E. Davis (g), L. W. Furness (cg), F. H. Klaer, Jr. (g), P. McGrain (g), F. C. Mikels (g), B. Moulton (c), J. I. Perrey (g)
Lafayette--R. B. Hickok (g), H. Kohnke (g), F. L. Serviss (abcefgh), N. L. Stoltenberg (g)
Richmond--D. R. Coates (fg)
South Bend--P. E. K. Fan (g), S. Kolupaila (g), A. J. MacAlpin (bcefgh)
Terre Haute--H. C. Crowe, Jr. (ce), R. A. Pohly (abcdefgh), W. H. Westerman (abcdfh)

Iowa

Ames--J. M. Aikman (cg), G. L. Barger (cg), J. S. Dodds (acg), P. H. Elwood (g), G. W. Fox (bcd), R. K. Frevert (cg), C. S. Gwynne (bfgh), A. R. Kassander, Jr. (bg), D. Kirkham (cg), J. E. McDonald (c), R. A. Norton (g), R. V. Ruhe (fgh), G. O. Schwab (cg)
Council Bluffs--J. V. Barnes (fg)
Des Moines--S. E. Decker (c), W. T. Hodge (cg), C. E. Lamoureux (c), C. R. Pettis (g), A. T. Steele (c)
Iowa City--M. C. Boyer (g), F. M. Dawson (cg), H. G. Hershey (cfgh), J. W. Howe (g), R. M. Jeffords (g), C. W. Lane (g), E. M. Laursen (g), P. Lin (g), C. J. Posey (g), J. J. Runner (fh), A. Spengo (gh), A. C. Tester (eg), A. C. Trowbridge (cefgh)
Mount Vernon--E. E. Moots (gh)
Seymour--G. M. Ruby (bf)

Kansas

Coffeyville--W. E. Sell (abd)
Council Grove--H. R. Imle (bd)
Fort Leavenworth--C. H. Elges, Jr. (cg)
Fredonia--W. L. Stryker (adfh)
Kansas City--E. J. Minser (c)
Lawrence--V. C. Fishel (c), J. C. Frye (g), R. C. Moore (efh), G. C. Prescott, Jr. (g), Ada Swineford (fg)
Manhattan--C. L. Englehorn (g), A. W. Zingg (g)
Mission--J. P. McCallister (g), J. H. Strub, Jr. (cg)
Overland Park--W. J. Ware (g)
Smith Center--R. A. Clark (ceg)
Topeka--S. A. Deel (d), R. A. Garrett (acg), J. E. Schrock (abcdefgh)
Wichita--J. R. Berg (fh), J. G. Blythe (fgh), C. K. Crum (c), R. C. English (b), W. C. MacQuown, Jr. (abd), L. C. Morgan (abcdfgh), K. G. Redman (abcdefgh), R. F. Walters (gh)

Kentucky

Bowling Green--W. D. Chawner (bdh)
Fort Knox--S. H. Birdseye (a)
Fort Thomas--J. W. Bruce (bg)
Henderson--E. J. Harvey (fg)
Lexington--Louise B. Freeman (e), W. R. Hamon (c), J. W. Huddle (eg), K. O. Lange (c), A. C. McFarlan (bh)
Lyndon--E. G. Barron (g)
Louisville--L. Beckner (abefh), W. S. Conaway (g), J. P. Davis (g), F. B. Harkness (cgh), H. E. Herman (cg), R. W. Kellogg (g), A. A. Lane (c), Matthew I. Rorabaugh (g), F. F. Schrader (g), A. F. Thiele (cg), E. H. Walker (g)
Paintsville--J. A. Baker (g), W. E. Price, Jr. (g)

Louisiana

Alexandria--O. Wendenburg (b)
Barksdale AFB--B. A. Bove, Jr. (c)
Baton Rouge--H. B. Brown, Jr. (abcefgh), H. M. Cox (aeh), J. S. Cragwall, Jr. (g), J. W. Gambrell (g), R. L. Geyer (bh), D. L. Glasscock (g), F. N. Hansen (g), E. L. Hendricks (g), G. R. Henson (bh), H. V. Howe (abdefgh), J. Huner, Jr. (eh), P. H. Jones (g), A. E. McGrew (c), D. R. Meier (a), G. E. Murray (abe), C. K. Oakes (g), R. J. Russell (acegh), I. L. Saveson (g), K. Wang (bgh)
Franklin--L. C. Adams (bd)
Grand Isle--W. W. Hildreth, Jr. (ceg)
Homer--G. D. Cloepfil (b)
Houma--G. Augustat (b), F. H. Hammons (abcd)
Lafayette--H. R. Conley (bc), H. F. Crain (abdeh), J. E. Lee, Jr. (b)
Lake Charles--R. H. Cowie (bd), H. J. Jones (bh)
New Orleans--G. I. Atwater (bh), F. A. Benedetto (d), W. R. Chalker (cg), I. M. Cline (ce), G. F. Collins (ce), C. J. Courtney (a), W. A. Eggler (cf), J. H. Foster (g), A. H. Glenn (ceg), C. F. Grubb (bh), J. F. Harang (abcdefgh), A. G. Harvey (b), H. N. Hickey (bce), B. B. Hughson (ab), R. I. Levorsen (bceh), K. A. Maring (b), J. C. McCampbell (abcdefgh), H. G. Meginnis (g), F. W. Oudt (bh), W. S. Pike, Jr. (bfh), R. Sanders (c), P. T. Seashore (abg), K. Shisler (ce), F. E. Simmons, Jr. (bg), N. J. Smith (bdfh), G. K. Stephenson (g), W. R. Stevens (c), J. W. Texter (b), W. E. Ware (abcdefgh), B. N. White (cg), W. B. Wiley (b)
Shreveport--G. J. Baker (dh), R. B. Baum (b), B. W. Blanpied (befh), P. A. Bloomer, Jr. (bh), C. L. Bryan (abcdefgh), K. Carter (b), O. Fickeissen (acg), R. T. Hazzard (abefh), G. C. Howard (abcdh), B. B. Hunkapiller (abcdefgh), D. T. MacRoberts (cg), A. E. Mix (bd), C. L. Moody (bdfh), R. R. Rosenkrans (bfh), C. N. Valerius (h), A. J. Westland (bc)
Sulphur--J. A. Moore (abcdefgh)

Maine

Augusta--M. R. Stackpole (g)
Houlton--L. Pavilides (befh)
Orono--L. Goldthwait (eg), J. M. Trefethen (fgh)
Portland--J. M. McDonough (ag), N. Smith (h)
Westbrook--H. S. Shaw (acde)

Maryland

Aberdeen Proving Ground--W. W. Berning (c), E. P. Duque (d), C. W. Lampson (f)
Annapolis--W. V. Burt (ce)
Army Chemical Center--W. S. Lanterman (c), S. D. Thayer (c)
Ashton--B. S. Richmond (e)
Baltimore--R. R. Bennett (g), G. S. Benton (ceg), F. L. Blue, Jr. (eg), D. E. Carritt (e), G. F. Carter (c), R. W. Chapman (cfh), E. Cloos (bfh), W. E. Davis (abd), J. P. Delaney (bcdh), Friez Instrument Division (Corporation Member), J. C. Geyer (ceg), W. H. Grant (f), A. A. Halff (g), E. J. Harned (g), H. E. Kuehn (d), F. W. Lee (abcdefgh), C. F. Merriam (g), R. R. Meyer (g), E. G. Otton (g), R. M. Overbeck (g), W. D. Parkinson (d), R. L. Pendleton (g), D. J. Portman (c), D. W. Pritchard (ce), K. A. Pullen, Jr. (d), F. Rasetti (d), R. Raspet (bcdf), C. E. Renn (e), W. H. Rhodes (d), Claire A. Richardson (g), I. Roman (abdh), J. W. Siegmund (eg), F. B. T. Siems (abde), J. T. Singewald, Jr. (abfgh), V. P. Sokoloff (g), J. H. Swartz (abcdefgh), A. Wolman (cg), L. M. G. Wolman (cg)
Beltsville--D. D. Mason (ag)
Berwyn--D. F. Bleil (de), C. H. Hardison (cg), R. W. Moore (bdg)
Bethesda--L. V. Berkner (cd), C. A. Betts (g), J. C. Bryant (cg), M. W. Buell, Jr. (ae), A. L. Day (bfh), D. F. Horton (e), W. C. Jacobs (ceg), W. L. Molo (c), C. H. Pierce (c), R. W. Schloemer (cg), W. H. Simonson (acg), N. Smith (d), H. S. Thomas, Jr.,(g), R. M. Wilson (a)
Brentwood--A. L. Shands (ceg)
Capitol Heights--C. H. Swick (aeh)
Cheltenham--J. B. Townshend (d), R. L. Viets (d)
Chester--L. R. Hafstad (d)
Cheverly--W. C. Hall (d), G. E. Harbeck, Jr. (cg)
Chevy Chase--H. K. Armstrong (g), B. Bird (g), S. W. Boggs (cg), M. F. Burrill (c), E. J. Chernosky (bcd), G. V. Cohee (de), J. H. Dellinger (d), B. Frank (g), R. E. Gibson (bcf), R. S. Goodridge (cg), E. A. Johnson (dh), H. F. Johnston (cdeh), R. B. Kennard (c), M. A. Mason (eg), E. R. Middleton (a), J. A. O'Keefe (a), L. M. Prindle (f), Jessica D. Stewart (abdfh), J. M. Symons (e), G. D. Whitmore (a)
Clinton--R. G. Stone (cg)
College Park--D. F. Dougherty(g), F. F. Le Fever (g), H. C. S. Thom (cg)
Conowingo--R. E. Turner (cg)
Cumberland--D. J. Lewis (abcdefgh)
East Riverdale--L. F. Hubert (ceg)
Frederick--V. W. Bartlett (c)
Fulton--J. V. Atanasoff (bcdefh)
Garrett Park--Frederic W. Darling (a), F. L. Weaver (g)
Gaithersburg--E. L. Williams (a)
Glen Arm--L. E. Wood (c)
Greenbelt--W. H. Klein (c), M. O. F. Schroeder (ce), I. Solomon (c), Ethel M. Wilson (g)
Hyattsville--W. J. Dichtel (d), A. B. Fuller (g), R. Gornitzky (a), T. I. Gray, Jr. (c), G. A. Hathaway (cgh), J. J. Matzko (fg), K. M. Nagler (c), V. J. Oliver (c), C. M. Roberts (fgh), G. C. Sherlin, Jr. (cdg), A. B. Taylor (g), R. N. Wilson (g), B. D. Zetler (e)
Indian Head--H. G. Snay (e)
Kensington--L. R. Alldredge (d), A. W. Postel (h), R. L. Rector (eg), F. S. Warner (g)
Lanham--C. S. Scofield (g)
Mt. Rainier--R. C. Doolittle (abdfh), J. S. Winston (c)
Owings Mills--F. C. Farnham (dh)
Riverdale--R. T. Zoch (cg)
Rogers Heights--A. Miller (c)
Salisbury--W. C. Rasmussen (bcg)
Silver Spring--R. F. Ackermann (a), B. O. Bogert (dh), C. B. Brown (g), A. Carnvale (a), A. L. Cochran (g), C. L. Cooper (eg), W. I. Duvall (bh), Hazel Edelman (cdfh), A. M. Erickson (d), G. T. Faust (bf), M. S. Gurnee (ceg), E. L. Hain (ae), H. L. Hamilton, Jr.,(c), J. R. Henderson, Jr. (d), A. F. Johnson (g), M. A. Kohler (cg), J. A. Kuhn, Jr. (abcd), B. S. Melton (b), A. G. McNish (cdfh), E. F. Preece (cg), D. A. Rice (a), F. Ronne (abcdefgh), H. E. Schwarz (g), W. O. Smith (dgh), Janet Snyder (cde), C. Swigart (g), O. Tenenbaum (c), M. H. Trytten (d), J. A. Van Allen (cd)
Takoma Park--J. N. Adkins (bd), H. W. Hobbs (cg), S. M. Johnson (adef), S. Pepper (acde), A. Rosenbloom (cgh), B. L. Snavely (be), H. C. Woster (cg)
Towson--B. C. Goodell (cg), S. S. Haynes (c)
Washington Grove--S. L. Seaton (cd), L. E. Shmidl (a)
West Hyattsville--G. E. Andreasen (cg)
White Oak--F. N. Frenkiel (ce)

Massachusetts

Amherst--P. A. Chenoweth (h), C. E. Gordon (f), G. A. Marston (acg), M. P. White (be)
Arlington--E. T. Allen (f), A. L. Aden (cd)
Auburn--D. P. Martineau (ce)
Auburndale--J. A. Shear (ce)
Bedford--C. E. Stearns (f)
Belmont--M. Greenberg (c), C. F. Jenkins (c)
Boston--R. C. Cowen (c), I. B. Crosby (bcefgh), K. G. Crosby (ae), H. N. Halberg (g), P. F. Howard (g), L. Katona (cg), H. B. Kinnison (cg), C. E. Knox (g), J. B. McAleer (g), M. T. Nesmith (c), K. Segerstrom (afg), K. C. Spengler (c), H. M. Turner (g), W. F. Uhl (g), C. W. Wolfe (befgh), G. K. Wood (g)
Bridgewater--P. Huffington (c)
Brookline--F. L. Olmsted (g)
Cambridge--J. M. Austin (c), A. E. Benfield (h), H. B. Bigelow (e), M. P. Billings (afh), F. Birch (bfh), F. T. Bodurtha (c), P. W. Bridgman (b), A. Casagrande (g), G. L. Clarke (e), R. A. Craig (cde), A. P. Crary (abdh), R. A. Daly (bfh), G. M. Fair (g), H. W. Fairbairn (fh), A. T. Fernald (c), F. L. Foster (bd), C. Frondel (h), A. T. Gifford (cg), P. G. Goldberg (c), L. C. Graton (fh), N. A. Haskell (bh), D. Hoffleit (cd), H. G. Houghton (ce), P. M. Hurley (fh), A. T. Ippen (eg), G. C. Kennedy (fh), H. Lake (ceg), L. F. Markus (c), K. F. Mather (befh), H. E. McKinstry (fh), D. H. Menzel (d), J. M. Mitchell, Jr. (bcf), F. K. Morris (efgh), D. T. Prophet (c), I. I. Schell (c), H. J. Shea (a), H. B. Silsbee (d), H. C. Stetson (e), H. A. Thomas, Jr. (g), F. L. Whipple (ac), W. L. Whitehead (h), H. C. Willett (ce)
Canton--A. W. Mackiernan (d)
Concord--Gertrude W. Dyer (dg), N. G. Parke, III (d), D. G. Smith (c)
Danvers--B. C. Wickham (c)
Dorchester--R. M. Rados (c)
East Boston--M. J. Finnegan (abcdefgh)
East Milton--R. W. Stewart (acegh)
East Weymouth--C. H. Minehan (g)
Falmouth--L. A. Cheney (e)
Kingston--G. N. Bailey (cg)
Lexington--W. E. Howell (c), M. E. Willard (fh)
Lincoln--D. W. Mann (ac), R. M. Tripp (bdh)
Lowell--V. F. Clark (c)
Marblehead--F. Sanders (c)
Mattapan--J. Biederman (c)
Medford--S. S. Ballard (df)
Melrose--J. G. Bryan (c)
Milton--C. F. Brooks (ceg), S. P. Fergusson (cg), I. F. Hand (c)
Newton Center--J. S. Pfeil, Jr. (c), G. W. Pickard (d)
Newton Highlands--A. P. G. Peterson (acd)
Newtonville--H. H. Lettau (cdeh)
Northampton--M. Schalk (ce)
Orange--W. K. Starr (g)
Peabody--J. W. Corbett, Jr. (c)
South Dartmouth--H. E. Cramer (c), E. W. Hewson (c)
South Duxbury--R. M. Field (abcdefgh)
Springfield--R. D. Ley (cg)
Sudbury--J. G. Wolbach (d)
Waltham--D. C. Bradford (bch), N. C. Gerson (cd), I. I. Gringorten (c), J. A. Peoples, Jr. (bdeh)
Watertown--F. C. E. Oder (c), E. S. Wood, Jr. (a)
Wellesley--M. E. Lunchick (g), R. B. Smith (c)
West Medford--R. L. Nichols (f)
West Tisbury--G. Duys, Jr. (e)
Weston--D. Linehan (abh)
Williamstown--F. Foote (bef), W. I. Milham (cdg), E. L. Perry (bfh)
Winchester--H. K. Barrows (g)
Woods Hole--D. F. Bumpus (e), F. C. Fuglister (e), J. B. Hersey (abdh), C.O'D.Iselin (ce), B. H. Ketchum (e), W. G. Metcalf (e), A. R. Miller (e), M. J. Pollok (ace), R. L. Rather, Jr. (bde), A. C. Redfield (e), Mary sears (e), H. R. Seiwell (begh), E. H. Smith (ceg), F. M. Soule (de), H. Stommel (e), A. C. Vine (ae), W. S. von Arx (ed), A. H. Woodcock (e), R. F. Wyrick (e)

Michigan

Adrian--Helen L. Foster (ch)
Ann Arbor--Dorothea Ammerman (cg), F. Anderegg (a), R. L. Belknap (cgh), H. Bouchard (a), E. F. Brater (g), S. D. Dodge (ace), B. W. Gibson (g), E. N. Goddard (f), E. W. Heinrich (f), W. H. Hobbs (bcefgh), R. C. Hussey (ae), G. Kiss (c), K. K. Landes (efg), Carol N. Macha (def), R. L. McNamee (g), H. W. Neill (cd), F. S. Turneaure (f), H. A. Weggel (g), J. T. Wilson (bch), C. O. Wisler (g)
Calumet--H. R. Cornwall (fh), W. S. White (h)
Cassopolis--B. P. Bishop (d)
Detroit--J. P. Bedford (fgh), R. D. Coons (c), O. O. Fisher (f), L. V. Garrity (g), H. F. Lawhead (abc), C. E. Lee (e), H. Mandelbaum (ceg), A. J. Mozola (bg), W. H. Parsons (fh), R. H. Wesley (h)
East Lansing--W. D. Baines (g), S. G. Bergquist (efg), R. E. Dils (g), A. E. Erickson (g), W. G. Keck (d), E. H. Kidder (g), Jane E. Smith (efg), R. G. White (g)
Grand Rapids--Natalie Bochenek (c), P. E. Johnson (c)
Houghton--L. O. Bacon (abdf), J. Fisher (bcd), W. A. Longacre (bdgh), S. Shulits (ceg), A. K. Snelgrove (bf), S. W. Wiitala (g)
Highland Park--C. L. Pien (g)
Iron Mountain--G. B. Patrick (c)
Iron River--H. L. James (df)
Ishpeming--E. Beutner (cg), B. H. Boyum (abcdefgh), E. A. Brown (g), W. T. Stuart (g), J. S. Sumner (abdfh)
Jackson--M. S. Harvey (g)
Kalamazoo--R. A. Sanderson (g)
Lansing--T. Abrams (a), N. F. Billings (acg), J. G. Ferris (g)
Midland--G. H. Hautau (abdh)
Mt. Pleasant--G. C. Sleight (abd)
Nazareth--B. E. Dethier (de)
Pontiac--Helen W. Dodson (d), R. R. McMath (adh)
Saginaw--C. G. Rowe (gh)
Sturgis--R. J. Miller (c)
Ypsilanti--G. W. Brock (c)

Minnesota

Albert Lea--P. C. Thompson (ac)
Beardsley--G. Hundeby (c)
Duluth--J. B. Hustad (d), H. L. Sundling (cg)
Heron Lake--A. D. Sontag (b)
Minneapolis--A. G. Anderson (g), H. W. Beresford (c), W. S. Cooper (g), R. M. Cornell (g), D. M. Davidson (d), S. S. Goldich (f), J. W. Gruner (f), G. O. Guesmer (ag), B. L. Hansen (cg), J. S. Holdhusen (g), L. A. Johnson (g), D. B. Lawrence (cfg), A. F. Meyer (cg), H. M. Mooney (abdfh), H. M. Morris, Jr. (cgh), M. M. Newman (cd), D. A. Parsons (g), J. Piccard (c), F. J. Ryder (cg), G. M. Schwartz (fgh), J. W. Shuman (cg), A. F. Spilhaus (ce), L. G. Straub (g), J. C. Weaver (ce), D. T. Williams (c), H. E. Wright, Jr. (cegh)
St. Paul--E. W. Bennison (g), K. F. Bickford (befgh), B. R. Colby (cg), G. Corwin (fh), J. J. Dolan (b), R. W. Gerdel (cg), W. S. Glock (cefg), A. L. Greenlee (g), W. E. Gustafson (g), K. S. Herness (dfh), C. L. Larson (g), M. E. Nelson (aeg), S. M. Rubens (d), R. Schneider (g), L. W. Sheridan (c), W. W. Wetzel (d)
Virginia--E. A. Hurd (c)

Mississippi

Carthage--E. L. Grimes (acg)
Jackson--E. J. Callan (bh), R. W. Farlee (bh), W. B. Fazakerly (ab), G. V. Fish (ceg), B. Mather (fh), Katharine Mather (efh), E. E. McCoy, Jr. (ch), E. M. Ross, Jr. (bfh), S. W. Totten (bdh)
McComb--M. D. Wickerham (b)
Natchez--J. G. Ferguson, Jr. (h)
Oxford--H. D. Burke (g)
Pascagoula--P. P. Sun (aceg)
State College--H. von H. Flinsch (ceg), A. Raspet (bcdh)
Vicksburg--F. Bayley, Jr. (g), F. R. Brown (g), A. R. Duncan (cg), M. J. Hvorslev (eg), R. E. King (cg), J. B. Leslie, Jr. (g), T. J. McMillan (a), N. R. Moore (cgh), W. R. Perret (bd), W. E. Rater (cg), W. H. G. Roth (cg), J. E. Sanders (cg), G. P. Weber (c), E. J. Williams, Jr. (g)

Missouri

Brentwood--G. K. Hasegawa (g)
Buckner--R. E. Johnson (g)
Clayton--H. M. Reitz (gh)
Columbia--W. L. Decker (cg), C. D. Holmes (cegh), W. D. Keller (fh), H. C. McComb (bcg), D. D. Smith (g), H. W. Wood, Jr. (g), C. M. Woodruff (g)
Ferguson--C. E. Parker (c)
Glendale--W. L. Northrop (cg)
Independence--K. V. Taylor (abgh)
Joplin--G. M. Fowler (b)
Kansas City--V. Alexander (g), W. R. Astleford (g), J. M. Barton (abh), J. A. Browne (c), W. G. Fish (g), A. M. Kahan (cg), J. R. Kinney (g), L. E. Nelson (acg), D. E. Phillips (cg), C. A. Stone (g), C. F. Van Thullenar (ceg), N. T. Veatch (g)
Kirkwood--J. R. Cullings (cg), C. K. Reynolds, Jr. (bc)
Normandy--J. A. Volk (bd)
Rolla--H. C. Beckman (g), S. L. Blanton (e), H. C. Bolon (g), V. G. Gabriel (abdefh), O. R. Grawe (efg), D. Kennedy (a), J. L. Rosenfeld (fh), J. K. Searcy (g)
St. Louis--G. C. Allen (cdeg), H. W. Ball (c), J. C. Berkenbosch (g), V. J. Blum (abcdh), E. M. Brooks (ceg), D. Clark (c), A. L. Forst (c), A. J. Frank (bdfg), T. E. Haeussner (cg), P. J. Harney (c), R. R. Heinrich (bc), N. S. Hinchey (bg), K. A. Holke (afgh), P. M. Honnell (b), W. W. Horner (cg), B. Howard (g), S. W. Jens (g), F. Klein (ag), C. E. Lewald (g), P. Light (cg), J. B. Macelwane (abcd), H. F. Mondschein (cg), L. C. Peltier (c), F. F. Pilotte (bc), W. E. Ray (cg), G. W. Reynolds (c), Florence Robertson (abdh), W. H. Roschke, Jr. (cg), H. L. Scharon (bdfgh), G. M. Sowers (fh), W. F. Sprengnether, Jr. (Sprengnether Instrument Co. representative), Sprengnether Instrument Co. (Corporation Member), N. H. Stearn (dh), C. W. Thomas (e), G. J. Vencill (cg), H. F. Wahlgren (c), A. L. Worseck (cg), W. H. Worseck (cg)
University City--C. Kisslinger (b)
Webster Groves--Lydia E. Curtis (c), J. N. Stephenson (cg), J. T. Sturm, Jr. (cg)

Montana

Billings--M. E. Bunger (ag), L. H. Dicke (cg), L. S. Gardner (abdfh), P. Q. Gibbs (cg), J. D. Goshorn (g), A. C. Hornung (bcg), C. H. Jennings (cg), K. R. Melin (g), P. A. Rechard (acg), F. A. Swenson (g), E. O. Wilson (g)
Bozeman--A. R. Codd (cg), E. R. Dodge (cg), P. W. Jordan (a), O. W. Monson (cg)
Butte--G. H. Ellis (g), S. W. Nile (b)
Dillon--W. H. Atwood, Jr. (ab)
Fort Peck--T. R. Carr (g), R. Oehler (g)
Glacier Park--W. R. Demme (g), J. R. Heller (cg)
Great Falls--A. G. Alpha (g), A. F. Bateman, Jr. (gh), E. P. Beaulieu (abcefgh), C. E. Erdmann (fgh), W. B. Price (c), T. R. Smith (g)
Helena--R. A. Dightman (c), C. S. Heidel (g), N. J. Holter (e), F. Stermitz (g)
Kalispell--C. S. Hazen (g)
Missoula--M. E. Baudendistel (g), A. E. Helmers (cg)
St. Ignatius--F. H. Tyro (cg)

Nebraska

Ainsworth--J. G. Cronin (abfg), K. J. Zentner, Jr. (g)
Bellevue--G. N. Gosewich (c)
Cambridge--G. L. Whitaker (g)
Grand Island--I. W. Bauer (cg), S. T. Fleharty (c), J. F. Mayne (cg)
Hastings--J. A. Allis (g)
Holdrege--D. W. Brown (gh)
Indianola--H. R. Bentley (cg)
Kearney--H. E. Sawyer (cdegh)
Lincoln--P. C. Benedict (g), R. G. Bowman (c), W. L. Cowan (ag), F. L. Duley (cg), R. A. Dyke (ceg), O. H. Gish (cdfh), L. M. Glymph, Jr. (g), R. A. Graham (abcdefgh), H. G. Heinemann (g), J. C. Jensen (cd), A. I. Johnson (g), C. F. Keech (g), L. L. Kelly (cg), A. L. Lugn (cg), A. P. Mazurak (g), V. Mockus (cg), R. E. Oltman (g), E. C. Reed (g), K. M. Sandals (cg), O. J. Scherer (g), E. F. Schramm (cef), H. A. Swenson (g), G. H. Taylor (g), R. B. Vice (g), H. A. Waite (acgh)
McCook--E. Bradley (g)

Nebraska--Concluded

Omaha--C. J. Ackermann (acdg), A. L. Alin (abcefg), D. C. Bondurant (cg), B. W. Brown (fh), F. B. Campbell (cg), J. P. Edstrand (cg), G. C. Gibson (cg), T. E. Huddleston (ag), K. Jetter (g), F. T. Johnston (h), M. E. Kirby (bdfgh), A. V. Leppanen (g), E. W. McClendon (c), B. T. Mitchell (cg), R. J. Pafford, Jr. (cg), C. R. Pelto (fgh), E. Soucek (cg), E. F. Stapowich (ce), R. N. Towl (g), O. B. Van Horn (cg), T. Waara (g)
Superior--J. J. Schmidt (cg)
Trenton--R. I. Alley (cg)

Nevada

Boulder City--F. S. Anderson (g), M. Diamond (cg), R. F. Kaser (g), T. C. Mead (abceg), H. E. Pelham (cg), W. R. Slater (g), J. W. Stanley (g), C. P. Vetter (aeg),
Carson City--W. Arnold (a), T. E. Eakin (g), T. W. Robinson (gh), G. A. Thompson (h), D. E. White (fgh)
East Ely--T. E. Rowley, Jr. (c)
Elko--S. J. Kriz (h)
Fallon--R. B. Morrison (bgh)
Kimberly--G. B. Maxey (g)
Reno--H. P. Boardman (g), J. E. Church (ceg), P. S. Cowgill (g), V. P. Gianella (bfg), C. E. Houston (acg), M. R. Miller (g), J. T. Ryan (g)
Silver Peak--H. H. Hughes (d)

New Hampshire

Dublin--R. Sagendorph (a)
Durham--D. H. Chapman (acg), L. T. Kardos (cg), T. R. Meyers (fg)
Goffstown--J. V. Salo (cdg)
Hanover--J. B. Lyons (f)
Newmarket--C. J. Schneer (af)

New Jersey

Alpine--S. Paige (abg)
Asbury Park--A. Arnold (c), H. Weickmann (cdg)
Atlantic City--W. J. Remillard (c)
Boonton--G. J. Fallon (aeg)
Deal--M. Ference, Jr. (cdh), J. C. Schelleng (d)
Elberon--P. Newman (cd)
Fair Lawn--H. A. Panofsky (c)
Franklin--A. W. Pinger (dh)
Highland Park--T. C. Nelson (ceg), A. S. Wilkerson (f)
Hoboken--C. W. Keuffel (Keuffel and Esser Co. representative), Keuffel and Esser Co. (Corporation Member)
Lakehurst--F. E. Courtney, Jr. (ce)
Leonia--J. L. Kulp (e), C. K. Wilcox (c)
Lincoln Park--E. B. Douglas (bdh)
Maplewood--J. M. Robbins (ag)
Montclair--E. W. Gilbert (bef)
Montvale--W. Jardetzky (h)
Murray Hill--W. A. Marrison (a)
New Brunswick--H. Bader (g), E. Reinhold Biel (cg), H. Johnson (eg), O. R. Neal (g), G. Winchester (ch)
Newark--H. C. Buckelew (bdfh), H. Levy (cg)
Palisade--H. M. Frazier (c)
Parlin--G. L. E. Linn (g)
Paterson--N. J. Heines (bcd)
Plainfield--A. C. Hawkins (c)
Princeton--A. F. Buddington (fh), J. G. Charney (c), A. W. Friend (cd), A. O. Hayes (bfh), H. H. Hess (abefh), S. B. Irish (a), P. Kissam (a), B. F. Leonard, III (dfh), P. MacClintock (eg), J. C. Maxwell (bdfh), R. Miller, III (f), E. Sampson (fh), P. K. Sims (fh), L. Spitzer, Jr. (cde), W. T. Thom, Jr. (abdfh), R. Vajk (abdh), H. F. Winterkorn (cg)
Princeton Junction--J. L. Richey (cd)
Rutherford--Audrey M. Arzinger (d)
Seabrook--M. H. Halstead (c), C. W. Thornthwaite (cg)

New Jersey--Concluded

Short Hills--W. W. Betteridge (cg), H. Herpers (eg)
South Orange--H. A. Foster (g)
Spring Lake--H. H. Waesche (bf)
Summit--H. D. Hedberg (abdeh)
Trenton--H. C. Barksdale (cg), H. T. Critchlow (cg), R. E. Cyphers, Jr. (g), M. E. Johnson (abdg), J. M. Ludlow (g), E. G. Miller (cg), G. R. Shanklin (cg), W. T. Sittner (g)
Upper Montclair--H. E. Hallborg (d)
Vineland--R. B. Campbell (bde)
West Englewood--T. Zuschlag (d)
Westfield--R. B. Sosman (fh)
Wood-Ridge--A. W. Wakeling (c)

New Mexico

Albuquerque--H. B. Allen (abdefgh), F. C. Ames (g), V. E. Arnold (g), H. Barnes, Jr. (fh), J. G. Breiland (c), R. H. Carter, Jr. (cg), C. S. Conover (cg), C. H. Diebold (g), J. H. Dorroh, Jr. (g), R. W. Fife (g), J. D. Hem (g), C. E. Hyvarinen (g), J. J. Idema (g), C. D. Johnson (h), V. C. Kelley (bdefgh), T. Meeks (g), J. D. Strobell, Jr. (abdfgh), C. V. Theis (g), S. A. Wengerd (abefh)
Artesia--C. A. Aston, Jr. (abd)
Aztec--G. B. Coan (b)
Carlsbad--A. L. Almy (abcdefgh), W. E. Pratt (bcefg), G. D. Riggs (d)
Los Alamos--T. J. Boyd, Jr. (cd), N. E. Bradbury (cd), R. W. Goranson (bfh), R. L. Griggs (fg), D. Johnstone (cg), D. D. Phillips (ah), H. K. Stephenson (bdef)
Portales--S. T. Martner (abdfh)
Roswell--H. E. Banta (bd), R. Crandall (dh), R. E. Murphy (gh), J. C. Yates (g)
Santa Fe--E. L. Barrows (g), W. T. Miller (g), G. L. Oakland (g)
Socorro--J. E. Allen (bf), E. Callaghan (bfh), W. D. Crozier (bd), S. M. Jones (bdefh), E. J. Workman (d)

New York

Albany--E. S. Asselstine (g), P. H. Bird (bd), D. B. Bogart (g), J. T. Breen (c), J. G. Broughton (fgh), J. J. Cassidy (cde), B. Dunn (g), Winifred Goldring (abcdefgh), I. G. Grossman (bfh), A. W. Harrington (cg), E. D. Hendricks (acg) J. E. Kerr (g), E. J. Saltsman (c), E. S. Simpson (g), R. C. Vorhis (bg), L. B. Yarger (g)
Amawalk--S. F. Kelly (abcdfh)
Averill Park--C. F. Romney (b)
Bayside--A. D. Henderson (eg), A. F. Merewether (c), M. Oppenheim (c)
Bellerose--H. J. Jordan (c)
Binghamton--H. K. Gold (ceg)
Boonville--L. Lansing (c)
Bronx--L. J. Brown (bd), Shirley Golden (c), E. M. Kovach (d), W. J. Pierson, Jr. (c), G. Rozanski (cefgh)
Bronxville--A. E. Parr (ce)
Brooklyn--I. Brill (cd), J. Bush (e), H. B. Churchill (b), W. L. Donn (ceg), J. F. Dracup (a), I. Greenberg (aceg), E. J. Gumbel (g), J. F. Hoffman (aceg), A. Charlotte Jackson (abcdefgh), M. Koenig (abce), K. E. Lowe (fh), B. Luskin (abcde), J. O'Halloran (bcdef), R. P. Papirno (c), N. M. Perlmutter (ag), E. J. Pluhowski (cg), L. Pocinki (ce), E. Lynn Savage (abfgh), E. M. Schlaikjer (ab), S. N. Stone (ad), A. J. Terzuoli (ce), C. A. Wright (eg)
Buffalo--W. P. Creager (g), F. S. Freeman (c), W. A. Hass (c), E. J. Kolkmeyer (b), H. H. Larkin, Jr. (c), A. C. McTigue (b), B. L. Wiggin (c)
Canton--R. O. Bloomer (fh)
Carle Place--H. D. Brice (g)
Chappaqua--L. C. Raymond (fg)
Chatham--J. T. Sherpey (c)
Cold Brook--E. Trevett (ch)
College Point--K. J. Hauser (c)
De Lancey--J. B. Westcott, Jr. (c)
Dobbs Ferry--G. N. Cox (g)
Ellenville--R. M. Sawyer (g)
Endicott--R. Digman (h)
Flushing--P. Lieber (bch)
Forest Hills--G. S. Leopold (cg)

New York--Continued

Fort Schuyler--M. H. Degani (cdeg)
Freeport--J. J. O'Neill (abcdefgh)
Garden City--F. Hunter (abde), V. Vacquier (abcd)
Glen Cove--F. D. Voris (cd)
Hamilton--J. G. Woodruff (b)
Hempstead--F. Field (bc), R. P. Heurich (g)
Hoosick Falls--G. P. Albergine (abg)
Huntington--A. H. Johnson (g)
Islip Terrace--R. C. Wanta (cde)
Ithaca--A. L. Anderson (cfh), G. R. Ayer (g), C. R. Burrows (cd), E. A. Engdahl (g), C. W. Gartlein (d), G. D. Harris (d), W. T. Holser (fh), H. C. Ladenheim (bcg), J. Lamb, Jr. (cg), G. B. Lyon (cg), C. M. Nevin (abdeh), F. C. Raney (c), C. W. Reck (g), P. H. Underwood (adegh), T. C. Wilson (abch), K. Yu (g), P. J. Zwerman (cg)
Jackson Heights--W. A. Bertrand (c), E. J. Clasby (c), L. Landau (ceg), C. S. Partridge (c)
Jamaica--W. J. Moxom (cgh), C. J. Neumann (c), I. T. Sanders (ae)
LaGuardia Field--L. Harmantas (ce), L. T. Olson (c)
Lake Success--C. W. Goyder (b)
Levittown--T. Arnow (g), W. E. Knight (c), C. M. Relyea (c)
Long Beach--C. I. Singer (cdeg)
Long Island City--D. F. Toomey (aefh)
Malverne--B. Shupack (ce)
Mineola--M. L. Brashears, Jr. (fgh), H. L. Frauenthal (gh), N. J. Lusczynski (g)
Mount Vernon--V. F. Hess (cd)
New York--H. A. Ackerman (ah), H. R. Aldrich (dfh), J. C. Armstrong (e), J. J. Baffa (g), B. A. Bakhmeteff (g), A. F. Banfield (dg), J. M. Beall (c), C. H. Behre, Jr. (fh), E. S. Belote (a), A. Bernstein (d), H. H. Beverage (d), M. A. Biot (bh), A. K. Blackadar (ceg), A. A. Brant (bcdgh), Renée M. Brilliant (ade), W. J. Brown (c), A. B. Bryan (abd), W. H. Bucher (ah), V. J. Burzi (c), F. A. Bush (abd), G. M. Byrum (c), A. J. Z. Caan (deh), Grace M. Carhart (f), B. N. Charles (cde), A. E. Cummings (g), G. G. Darkenwald (c), M. Datz (e), W. F. Davidson (cd), S. N. Daviess (bcefgh), V. P. de Smitt (abceh), C. L. Drake (abde), J. T. Duce (abd), M. A. Egazarian (ag), G. Emmons (ce), L. Espenschied (d), M. Ewing (abcdeh), G. Failla (d), N. V. Feodoroff (g), W. O. Field, Jr. (g), J. E. Fisher (abeg), S. K. Ghose (g), T. R. Gilliland (d), S. Goldman (d), E. A. Golomshtok (cg), B. H. Grove (abeh), G. R. Hamilton (abdeh), W. W. Hardy (abd), E. H. Harlow (eg), B. Haurwitz (cde), H. F. Haworth (g), G. H. Hazen (ab), R. Hazen (cg), B. C. Heezen (abdefh), C. V. Hendricks (bcdeg), Martha B. Heyde (ceg), J. M. Hildt, Jr. (cd), E. Holman (abd), P. H. Jaenichen (cg), B. D. Kane (c), S. Katz (bdeh), G. F. Kaufmann (abdh), M. Kay (eh), J. M. Kennedy (cgh), P. F. Kerr (f), P. Z. Kirpich (g), T. T. Knappen (cg), G. M. Knebel (beh), E. Koehler (c), S. A. Korff (cd), M. T. Kozary (abcdefgh), Patricia A. Langwell (ce), C. Lee (ceg), R. M. Leggette (g), L. B. Luhrs (b), A. M. Lunetta (g), J. J. Lynch (bh), W. A. Lynch (bdh), G. H. Lynn (ac), M. M. Macomber (e), M. R. MacPhail (abdh), G. H. Matthes (g), G. T. McCarthy (ceg), J. E. Miller (c), R. W. Miner (abcdefgh), R. D. Mollison (bdfh), T. V. Moore (be), R. E. Morehouse (ac), R. Nebolsine (g), A. C. Neumann (ceg), D. T. O'Connell (bcfh), C. B. Officer, Jr. (abe), J. E. Oliver (bce), W. S. Olson (abh), B. H. Oremland (c), J. E. Pfeiffer (abcdefgh), M. Pirnie (cg), F. H. Pough (f), F. Press (abdefh), R. R. Rapp (c), H. H. Rasche (c), A. P. Ratti (a), R. J. Rommer (c), C. F. Ruff (cg), J. H. Sanford (g), T. Saville (ceg), S. Saxon (bceg), D. C. Skeels (abdefh), K. G. Smith (bdg), V. Stefansson (ce), C. Stehle (abcdefgh), A. N. Strahler (g), M. H. Taylor (eg), H. D. Thompson (ah), C. Thor (c), I. Tolstoy (abdeh), A. S. Toth (g), F. E. von Estorff (bfh), L. G. Weeks (abcdefgh), C. M. Weiss (eg), G. E. Wheeler (g), G. R. Williams (g), B. O. Winkler (abdh), W. A. Wood (acg), C. P. Yerkes (bcg)
New Rochelle--A. S. Kussman (c)
Newtonville--E. J. Christie (cg)
Niagara Falls--R. C. Mitchell (adh)
Nyack--J. D. Edwards (bf)
Orangeburg--J. R. Smith (c)
Oswego--E. F. Loveridge (c)
Ozone Park--H. V. Kaska (abefgh)
Palisades--J. Northrop (e), J. L. Worzel (abde)
Parish--E. Church (a)
Peekskill--J. W. Irish (ag)
Riverhead--G. S. Wickizer (c)
Rochester--H. L. Alling (f), P. R. Jameson (bc), W. F. Jenks (fh), W. A. Noyes, Jr. (ex-officio), B. O'Brien (cd), J. M. Williams (cg)
Roslyn--S. E. Heiprin (bd)

New York--Concluded

Roslyn Heights--W. P. Willetts (abcdefgh)
Saratoga Springs--G. Kelton (bc), L. W. Strock (ef)
Scarsdale--B. F. Ellis (be), Mary W. Garretson (fgh), W. O. Hotchkiss (deh)
Schenectady--I. Langmuir (ceg), V. J. Schaefer (cg), E. S. C. Smith (bfg)
Scottsville--J. E. Hoffmeister (e)
Seaford--P. E. Kraght (c)
Slingerlands--R. Van Vliet (cgh)
Sparkhill--A. R. Platzer (c)
Stewart Manor--J. H. Nelson (d)
Syracuse--E. T. Apfel (cgh), N. E. Chute (efh), G. B. Cressey (cefg), P. E. James (c), H. V. B. Kline, Jr. (a), J. L. Kovner (cg), A. F. Sadowski (c)
Troy--R. P. Abrahams (b), R. F. Beers (abdefh), L. C. Higbee (ag), E. J. Kilcawley (g), H. R. Larsen (a), S. W. Lowman (abefh), J. L. Rosenholtz (abdfh), H. O. Sharp (a)
University Heights--J. Spar (c)
Upton--W. de Laguna (g), L. P. Hatch (g), P. H. Lowry (c), M. A. Warren (g)
Valhalla--F. J. Socey, Jr. (c)
Valley Stream--G. L. Shak (c)
Watertown--E. S. Cullings (g)
Webster--H. J. Schutt (c)
Wellsville--P. Donnerstag (abdfh)
West Albany--H. J. Smith (c)
West Point--W. S. Stone (c)
Westbury--G. J. Gray, Jr. (c)
White Plains--R. H. Dinegar (c), J. C. Harding (g)
Wingdale--W. G. Hoyt (cg)
Wyoming--G. Hartnell (bd)
Yonkers--R. B. McConnell (aceh)

North Carolina

Asheville--A. B. Goodwin (g), R. A. Hertzler (g), F. C. Hood (cg), C. E. Hunter (bf), C. R. Hursh (g)
Biltmore--H. J. Loughead (cg)
Chapel Hill--F. O. Bowman, Jr. (bfh), B. H. Grossman (c), G. R. MacCarthy (bdfgh), W. F. Rothwell (fh)
Charlotte--J. M. Howe (ceg), W. R. Tipton (ag)
Durham--W. Berry (acefg)
Elizabeth City--W. J. Cox, Jr. (ef)
Lenoir--S. Schworm (fh)
Nags Head--F. B. Dinwiddie (ceh)
Raleigh--W. B. Anderson (c), R. M. Harding (cg), J. L. Lamson (g), H. E. LeGrand (abdg), J. F. Lutz (g), E. L. Miller, Jr. (abcdefgh), E. B. Rice (cg), C. H. M. Van Bavel (g)
Shelby--W. R. Griffitts (fh)
Tryon--B. K. Couper (e)
Waynesville--M. J. Gilbert (cg), H. H. Jackson (cg)
Wilmington--P. Hess (c), R. W. Leonard (g), N. C. Magnuson (cg)

North Dakota

Bismarck--M. L. Dwight (g), H. M. Erskine (g), E. D. Gordon (g), D. W. Greenman (g), G. A. LaRocque, Jr. (g), H. C. McCreery (g)
Grand Forks--P. D. Akin (g), S. Aronow (g)
Mandan--J. R. McHenry (g)
Riverdale--H. K. Pratt (cg), F. S. Witzigman (g)

Ohio

Bowling Green--J. R. Coash (egh), L. R. Fletcher (cg)
Cincinnati--T. W. Bendixen (cg), K. E. Caster (aeh), A. T. Cross (eg), B. R. Gilcrest (g), L. P. Hahn (cg), E. A. Lawler (cg), R. Morgan (cg), J. L. Rich (abefh), M. M. Richards (cg), V. C. Stechschulte (bdh)
Cleveland--C. G. Andrus (cg), H. F. Birkenhauer (bc), H. F. Donner (acf), M. C. George (ceg), E. H. Hahn, Jr. (cdh), J. S. Joliat (bch), S. D. Lazarus (c), E. J. Walter (bc)

Ohio--Concluded

Columbus--R. L. Alkire (bc), R. J. Bernhagen (g), W. O. Byrd (a), C. C. Chambers (g), L. C. Crawford (g), A. d'Audiffret (cg), R. Davies (ag), P. Dehlinger (abch), R. K. Dodson (g), K. E. Etheridge (b), A. H. Frazier (ag), R. P. Goldthwait (bcgh), G. H. Harding (a), W. Hofmann (g), O. H. Jeffers (cg), P. Kaser (cg), R. G. Kazmann (g), J. C. Kennedy (g), R. G. Kouyoumjian (c), J. C. Krolczyk (g), W. L. Lamar (g), C. A. Lamey (defgh), W. P. Martin (g), J. H. Melvin (abgh), H. F. Morey (g), H. J. Pincus (ch), R. W. Powell (g), J. C. Prior (g), Ranney Method Water Supplies (Corporation Member), E. E. Sanderson (g), E. J. Schaefer (g), J. B. Schreiter (a), E. W. Silitch (g), G. R. Smith (cg), E. M. Spieker (gh), E. Van Cleff (cdh), E. E. Webber (g), R. F. Weisent (g), C. V. Youngquist (g)
Coshocton--F. R. Dreibelbis (g), L. L. Harrold (g), W. H. Pomerene (cg), L. Schiff (g), H. T. Stewart (ad)
Dayton--W. G. Alexander (c), R. E. Allen (bcg), C. S. Bennett (g), G. D. Colchagoff (df), J. J. Deeg (acd), M. M. Hopkins, Jr. (cd), B. M. Jones (cg), T. F. Kelley (c), J. F. Wall (c)
Delaware--N. T. Bobrovnikoff (a), W. P. Cross (cg)
Doylestown--H. J. Galehouse (c)
Findlay--P. M. Konkel (abdh)
Lakewood--O. B. French (abe)
Mount Vernon--O. S. Adams (a)
Oberlin--C. W. Carlston (g)
Put-in-Bay--J. L. Verber (g)
Struthers--C. H. Baldwin (cd)
Tipp City--G. T. Stephens (c)
Toledo--Margaret J. Applegate (bg), W. H. Miller (c)
Warren--P. F. Jacoby (c)
Wooster--K. Ver Steeg (abcdefgh)
Yellow Springs--G. H. Duncan (c), A. C. Swinnerton (bcdefgh)

Oklahoma

Ada--T. K. Treadwell, Jr. (de)
Ardmore--M. G. Hoffman (bfh)
Bartlesville--W. H. Courtier (abdeh), W. B. Weeks (bh)
Britton--N. G. Flaigg (g)
Duncan--F. Gouin (acg), W. B. Tapper (b)
Enid--R. L. Clifton (abef), C. M. England (bd)
Goodwell--H. H. Finnell (cg)
Midwest City--C. D. Bonnot (c)
Muskogee--R. A. Voegeli (bc)
Norman--J. A. Erdélyi-Fazekas (abdefh), C. L. Fair (g), H. E. Hoy (a), F. A. Melton (efgh), M. C. Oakes (fh), G. R. Pickett (b), E. W. Reed (g), S. L. Schoff (abcefh), W. Schriever (bcd), L. W. Stewart (d)
Oilton--O. S. Anderson, Jr. (a)
Oklahoma City--J. A. Ballard (abc), M. G. Barclay (ag), B. W. Beebe (bch), M. B. Berger (g), V. N. Brown (ab), R. Engleman (bh), R. M. Gardner (cd), T. H. Green (bch), T. C. Holt (abd), S. K. Jackson (cg), F. Janovy (dh), J. E. Kamitchis (abd), F. W. Kennon (g), J. A. Kornfeld (bdf), W. B. Perry (abdh), R. T. Pollard (g), W. R. Sype (ad), F. E. Wimbish (ag)
Okmulgee--R. K. Dodge (ab), G. G. McCulloch (abdefgh)
Ponca City--J. M. Crawford (a), D. E. Fickinger (b), H. Kaufman (bd)
Seminole--F. J. Smith (befg)
Shawnee--C. H. Ruff (d), W. F. Tanner (cegh)
Stillwater--W. O. Ree (g), H. E. Stocking (fh)
Tinker Air Force Base--C. G. Vaughn (c)
Tulsa--E. F. Bangs (d), A. J. Barthelmes (b), J. G. Bartram (bce), W. O. Bazhaw (ab), E. Beck (ab), T. J. Bevan (abdfh), W. T. Born (b), F. G. Boucher (bd), C. E. Buffum (b), F. F. Campbell (bh), D. W. Cochrane (b), R. C. Coffin (abcdgh), A. E. Coldwell (g), F. M. Cowell, Jr. (b), S. Cronin (bdh), W. J. Cunningham (b), A. R. Denison (beg), M. E. Denson, Jr. (abdefgh), P. A. Dickey (bdh), L. M. Dilts (cg), K. Dyk (bfh), D. G. Egan (bcdgh), J. D. Eisler (bd), A. W. Engle (abd), J. B. Etnyre (bdh), R. E. Fearon (abd), J. L. Ferguson (bce), C. Ferris (abch), R. S. Finn (b), C. H. Frost (a), S. W. Fruehling (b), Geophysical Research Corp. (Corporation Member), A. Gilmour (abdh), E. J. Handley (abcdefgh), C. J. C. Harvey (bgh), A. G. Hawkins (b), J. E. Hawkins (bd), C. L. Hays (a), A. J. Hickerson (cg), W. R. Holway (g), W. L. Horner (g), P. R. Jones (bcefh), V. L. Jones (abdh), K. K. Kimball (abdeh), V. J. LaForge (ab), T. A. Manhart (bd), J. R. Maxey (abdeh), C. H. McAlister (bd), E. V. McCollum (abh), A. L. McCuistion (b),

Oklahoma--Concluded

Oklahoma (concluded)--B. R. McKnight (ah), G. R. Morrow (bc), R. W. Mossman (b), A. N. Murray (befh), J. M. Nash (h), J. R. New (a), C. W. Oliphant (abdh), J. E. Owen (Geophysical Research Corp. representative), A. R. Patterson (b), S. Raborn, Jr. (ah), D. E. Reed (d), W. K. Rickel (bgh), N. Ricker (abcdh), R. J. Riggs (b), J. J. Roark (b), J. F. Rominger (egh), C. Ryniker (bdfh), G. D. Schedler (bh), S. A. Scherbatskoy (bd), M. E. Schmidt (g), C. B. Scott (b), Seismograph Service Corp. (Corporation Member), J. A. Sharpe (abdh), E. F. Shea (b), D. Silverman (abcdh), R. S. Tarr (bcefh), G. L. Taylor (abdh), R. R. Thompson (bd), H. M. Thralls (b), S. Von Croy (bd), R. J. Watson (abcdfh), B. B. Weatherby (bh), G. H. Westby (bd), M. B. Widess (abcdefgh), S. W. Wilcox (bcd), W. B. Wilson (bceh), E. A. Wyman (acgh)

Oregon

Bend--A. E. Perry (g), H. W. Sexton (fg)
Cannon Beach--G. H. Canfield (g)
Corvallis--A. W. Marsh (g), O. H. Meyer (g)
Foster--J. Summersett, Jr. (g)
Ione--K. J. Smouse (acg)
Klamath Falls--Elsie M. Barker (c)
Marcola--L. Paschelke (g)
Medford--R. T. Beaumont (cg), W. T. Frost (g), G. C. Taylor, Jr. (g), E. M. Tucker (b), R. A. Work (g)
Oregon City--D. L. Miller (g)
Portland--E. H. Bernstein (abde), I. Bloch (g), M. D. Brands (g), W. E. Bullard (g), M. H. Burke (g), E. J. Core (g), E. Fisher (cg), E. M. Flaxman (g), C. D. Hopkins, Jr. (g), C. E. Jencks (cg), A. H. Jones (c), G. A. Kirkpatrick (g), D. W. Kuehl (cg), F. H. Larson (g), R. R. Larson (c), N. H. Leupold (g), T. J. Maher (abdeh), A. Moore (g), E. C. Myers (cg), C. Pederson (cg), K. N. Phillips (cg), A. M. Piper (g), A. J. Polos (g), M. S. Sachs (g), V. P. Schermerhorn (cdg), A. L. Sharp (g), J. C. Stevens (g), F. D. Trauger (g), G. G. West (cg), D. A. Williams (g), H. G. Wilm (cg), J. Wimmer (abcdfh)
Rickreall--G. E. Van Santen (cg)
Roseburg--M. L. Caldwell (cg)
Salem--K. E. Anderson (fgh), C. E. Mohler (g)

Pennsylvania

Ambler--J. W. Mauchly (cd)
Bethlehem--N. Bethlahmy (eg), A. H. Fretz (ef), H. R. Gault (fh), R. D. Geisenderfer (c), G. R. Jenkins (ceg), H. C. Storey (cgf), B. Willard (bcefgh)
Bradford--R. C. Barber (bcdfh), E. T. Heck (abdegh)
Bryn Mawr--E. H. Watson (abfh)
Canonsburg--E. L. Sulkowski (bc)
Carnegie--J. T. Galey (abcdefgh)
Carrolltown--F. J. Lacny (c)
Chambersburg--J. L. Rosenberry (c)
Cheswick--Marie M. Tolmachoff (ch)
Clearfield--C. H. Keenan (bde)
Conestoga--E. T. Schuleen (g)
Conneaut Lake--J. Sherrod, Jr. (c)
Dover--W. E. Warner (ce)
Easton--J. L. Dyson (g)
Ebensburg--F. A. Bender (abcdefgh)
Erie--P. C. Wuenschel (ab)
Gibsonia--P. O. Fink (abcdefgh)
Harrisburg--A. W. Green (c), F. L. LeMert (g), J. W. Mangan (g)
Hatboro--J. Pfeffer (cg)
Haverford--G. F. White (g)
Havertown--J. C. Osmond, Jr. (b)
Johnstown--Dorothy G. Nitch (bc)
Johnsville--D. L. Arenberg (c)
Lewisburg--G. A. Irland (b)
Lewistown--D. G. Yerg (cdeg)
Lock Haven--H. F. Parker (g)
Mount Joy--K. L. Drohan (c)

Pennsylvania--Concluded

New Cumberland--L. F. Conover (cg), B. H. Russler (cg)
New Geneva--A. A. Thompson (bc)
New Kensington--F. Keller, Sr. (b)
Norwood--C. B. Bazzoni (bcdeh)
Oakmont--D. H. Smith (b)
Oreland--A. O. Quinn (a)
Palmerton--H. McMurry (abd), R. K. Waring (bd)
Philadelphia--H. P. Adams (cg), E. R. Armstrong (ce), K. A. Beck (c), N. C. Courtney (g), O. P. Ferrell (cd), J. B. Graham (g), J. G. Gruss (ag), H. Jensen (ad), J. C. Kammerer (gh), J. G. Kelley (a), H. Korkes (abc), N. R. Laden (g), R. W. Lenhard, Jr. (c), D. M. Ludlum (c), J. F. Mason (ah), W. D. Mason (cg), R. J. McCurdy (be), O. Rosenzweig (h), L. A. Shallow (c), A. W. Weeks (h), R. F. Weston (cg), T. Yen (gh), J. A. Young, Jr. (bdeh)
Pittsburgh--J. Affleck (abdfh), L. H. Bailey (aceh), B. B. Cox (cegh), D. A. De Woody (b), E. A. Eckhardt (abdh), T. A. Elkins (abdh), R. F. Ewald (cg), C. R. Fettke (befgh), F. H. Finn (h), P. D. Foote (bgh), L. W. Gardner (bh), W. B. Gealy (bfh), H. M. Gerber (c), S. I. Hammer (abdh), W. E. Hanson (efg), K. C. Heald (bd), R. J. Heredia (adeg), L. G. Huntley (bg), L. M. Laushey (g), E. A. Malone (bch), F. T. Mavis (g), E. H. Miller (g), G. I. Mulholland (c), M. Muskat (bdg), A. Nadai (bcefh), B. N. Netzer (cg), T. J. O'Donnell (abd), H. W. Patnode (gh), C. M. Patterson (cf), R. F. Pomeroy (abdh), T. L. Reilly (cg), R. G. Reiser (a), H. Rockwood (cg), R. E. Rogal (cg), R. E. Sherrill (befgh), J. E. Stewart (cg), D. W. Van Tuyl (g), W. E. Ward (bch), D. M. Weber (abdh), R. D. Wyckoff (bdg)
Roslyn--R. S. Dahlberg, Jr. (bdg)
Schuylkill Haven--C. F. Lindholm (g), V. E. Moyer (cde)
Scranton--R. E. Simmermacher (eg)
Sewickley--A. E. Allen (g)
Spring City--D. E. Whelan (abcdefgh)
State College--L. Berger (gh), C. T. Bressler (bcdefgh), J. C. Cook (bd), W. E. Eggert (c), C. L. Hosler (c), B. F. Howell, Jr. (abcdh), G. V. Keller (d), P. D. Krynine (egh), E. W. Miller (ac), H. Neuberger (bch), E. F. Osborn (fh), J. M. Robertson (ceg), C. J. Smith (g), K. Vozoff (abde), A. H. Waynick (d), B. A. Whisler (g)
Sunbury--W. R. Jones (g)
Swarthmore--F. K. Davis, Jr. (c), W. F. G. Swann (cd)
Upper Darby--A. Bevan (g), L. B. Corwin (cg), L. E. Miller (abcdefgh)
Williamsport--J. Courtney (c)
Wyncote--A. R. Mitchell, 3rd (c)
Wyomissing--C. S. Ling (c)

Puerto Rico

San Juan--T. L. Long (c), E. H. Marx (c)
Santurce--P. G. Ledig (d), L. A. Leyenberger (cg), G. Stallard (c)

Rhode Island

Kingston--C. J. Fish (eg)
Narragansett--D. L. Hazard (abd)
Newport--P. J. Bloom (c)
Providence--W. B. Allen (g), C. W. Brown (bcfh), A. C. Chick (bcg), C. Freeman (bf), A. W. Quinn (abfgh)
Riverside--F. E. Fahlquist (bgh)

South Carolina

Charleston--W. Candrick (cg), J. H. Watkins (abcdefgh)
Chesnee--W. C. Bowen (ag)
Clemson--D. D. Curtis (cg)
Columbia--W. W. Evett (g), A. E. Johnson (g), R. A. Miller (g), G. E. Siple (abefg), S. Taber (bcefgh), F. W. Wagener (g)
Pickens--T. J. Mitchell (ace)
Spartanburg--J. W. Roehl (g)
Union--M. D. Hoover (g)

South Dakota

Aberdeen--J. W. Newquist (abd)
Brookings--M. M. Fogel (g)
Hot Springs--H. F. Kroening (cg)
Huron--M. E. Von Seggern (g), W. H. Wells (c)
Newall--D. M. Jennings (abd)
Rapid City--E. L. Tullis (bdgh)
Vermillion--C. L. Baker (a), R. E. Stevenson (bf)

Tennessee

Alcoa--T. W. Kleinsasser (c)
Athens--M. S. Shadel (g)
Charleston--P. P. Fox (abh)
Chattanooga--W. R. Eaton (g), J. M. Terry (g), N. H. Williams (cg)
Elizabethton--E. S. Daly (g)
Fountain City--G. H. Hickox (g)
Gatlinburg--J. B. Hadley (bfh), P. B. King (bh)
Johnson City--R. L. Parson (aceg)
Knoxville--W. C. Ackermann (cg), C. T. Barker (bg), A. Blickensderfer (cg), W. A. Bowmaster (cg), G. D. Debuchananne (fg), A. S. Fry (cg), F. A. Horton (g), R. Hume (cg), B. C. Moneymaker (g), E. J. Rutter (g), J. Smallshaw (cg), F. G. Snyder (fh), W. M. Snyder (cg), J. H. Wilkinson (g)
Lebanon--C. Wells (g)
Limestone--W. K. Mahoney (c)
Memphis--W. H. Banks (cf), E. M. Cushing (g), C. R. Jobe (c), A. L. King (cg)
Nashville--H. J. Blazek (g), V. M. Doyle (c), J. A. Hageman (abdgh), W. C. McNeill (cg), C. W. Wilson, Jr. (a)
Norris--R. A. Elder (g), J. S. Rothacher (cg)
Oak Ridge--C. C. Moeller (cg)

Texas

Abilene--A. E. Barnes (abd), J. E. Brantly (ab), A. L. Jenke (g), B. F. Latch (abh)
Alpine--L. H. Henderson (fgh)
Amarillo--H. M. Britt, Jr. (b), A. C. Hornady (a), E. W. Rowland (g), P. L. Sharkey (cg), H. T. Trigg (g)
Austin--V. L. Austin (g), V. E. Barnes (aefh), D. W. Bloodgood (cgh), S. D. Breeding (g), W. L. Broadhurst (g), June E. Brooks (g), F. M. Bullard (ef), H. P. Bybee (ah), S. E. Clabaugh (fh), H. S. Coleman (c), G. G. Commons (cg), R. K. DeFord (g), W. W. Doyel (g), G. K. Eifler, Jr. (fh), C. E. Ellsworth (g), W. O. George (g), J. R. Gerhardt (ce), D. E. Havelka (cg), C. W. Horton (abh), D. S. Hughes (abeh), K. H. Jehn (ceg), D. B. Knowles (g), L. J. B. La Coste (ab), P. P. Livingston (g), J. T. Lonsdale (fgh), A. L. Orvis (cd), D. E. Outlaw (bdfh), Helen J. Plummer (e), H. C. Pritchett (g), J. W. Pritchett (acg), F. E. Romberg (bh), J. Paul Roston (bg), H. B. Stenzel (fh), I. M. Stout (abcdgh), R. W. Sundstrom (g), T. Twichell (g), W. N. White (g), K. Young (ah)
Bay City--A. H. Wadsworth, Jr. (bdfgh)
Beaumont--H. T. Austin (b), W. W. Davis (abcdegh), L. G. Ellis (abd), O. R. Gammon (abd), R. F. Hagemann (bdh), V. F. Jennemann (bc), H. R. McCormack, Jr. (bh), J. W. Millington (abd), B. E. Richert (d), J. A. Waller, Jr. (b), C. S. Wolston (ab)
Beeville--D. G. Barnett (abdh)
Bellaire--C. B. Crooker (cg), J. W. Fishback (ab), B. D. Lee (b)
Big Spring--C. F. Barnes (bdg)
Breckenridge--A. D. Dunlap (b)
Brenham--C. E. Curtis (g)
Brownfield--L. A. Woollett, Jr. (b)
Brownsville--J. C. Hagan (ceg), S. S. Nye (g)
Childress--W. J. Arnold (bcd)
Cisco--Robert E. Lee (abdfh), J. R. Reeves (b)
Coleman--M. G. Cheney (beh)
College Station--H. R. Blank (g), M. C. Hughes (cd), A. A. Jakkula (abcdefgh), D. F. Leipper (ce), S. A. Lynch (bdeg), J. G. Mackin (e), H. J. Miles (eg), W. A. Price (ceg), D. F. Weekes (bd)
Corpus Christi--J. T. Hartman (abdh), J. R. Randolph (bh), R. N. Spencer (abh), S. P. Weatherby (b)
Crystal City--J. W. Flanagan (g)

Texas--Continued

Dallas--C. C. Albritton, Jr. (bfgh), E. D. Alcock (b), O. H. Armstrong (b), K. Arnold (abcdefgh), M. Bigger, Jr. (b), W. C. Bonebrake (bd), H. H. Brown (b), K. E. Burg (abdh), J. A. Cathey (b), D. H. Clewell (bdeh), O. C. Clifford, Jr. (adh), H. L. Cobb (a), H. C. Cortes (b), C. G. Dahm (bdh), E. L. DeGolyer (bdeh), M. B. Dobrin (bdh), D. R. Dobyns (b), R. F. Dundon (b), J. C. Dunlap (eg), E. A. Fain (b), H. W. Feldt (acg), E. H. Finch (abd), F. K. Fisk (abcdgh), M. M. Garrett (abcdefgh), C. H. Green (b), P. E. Haggerty (bd), G. S. Hammonds (bd), W. J. Harkey (b), J. W. Harrington (dh), W. B. Heroy (abfg), W. B. Heroy, Jr. (abdh), W. B. Hogg (bh), P. L. Lawrence (bh), M. V. Linwell (b), L. B. Lipson (abdh), L. W. MacNaughton (eg), M. D. McCarty (bde), E. McDermott (bdfh), W. G. Meyer (bh), J. P. Minton (b), W. R. Mitchell (b), J. Moon (b), C. G. Morgan (bef), P. E. Nash (abcdefgh), N. Neece, Jr. (h), T. W. Nelson (abdgh), W. W. Newton (b), H. B. Peacock (abdh), J. W. Peters (abdh), C. P. Porter (abcdefgh), M. Quarles, Jr. (b), W. R. Ransone (abcfg), D. S. Renner (b), R. E. Rettger (abh), A. Richards (fh), J. F. Rollins (b), W. B. Roper (a), E. E. Rosaire (abdfgh), H. W. Rose (abdh), J. T. Rouse (f), E. R. Scott (bcdgh), G. F. Shepherd (bd), T. R. Shugart (bc), W. G. Smiley, Jr. (bd), E. F. Taylor (aeh), W. N. Tottenham (b), E. G. Trostel (abdh), J. A. Waters (bd), K. H. Waters (abd), R. R. Wheeler (abh), G. White (e)

El Paso--L. R. Flook, Jr. (g), R. L. Lowry, Jr. (cg), W. F. Resch (g), A. H. Witholder (g)

Fort Stockton--T. M. Culbertson (g)

Fort Worth--R. G. Andrews (g), F. L. Aurin (b), W. D. Baird (ab), W. R. Berger (bgh), E. L. Burnett (g), H. L. Collins (cg), R. H. Dana (b), D. Donoghue (g), S. W. Freese (cg), W. Grant (g), P. S. Groginski (abcdefgh), E. L. Hardy (cg), G. H. Harrington, Jr. (abdefh), S. Harris (b), M. A. Hartman (g), T. E. Henderson (g), L. Hendricks (fh), J. A. Hord (gh), H. E. Itten (b), J. F. Johnson (bdh), V. H. Jones (g), R. H. Lang (b), P. H. Ledyard (b), H. A. Ley (h), R. J. MacConnell (cg), H. Matson (g), E. R. McFarland (ad), A. E. McKay (b), Ethel W. McLemore (bg), C. Miron (g), J. G. Moore (ceg), J. Morgan (d), C. E. Roberts (g), F. H. Schouten (bd), J. H. Wilson (abdh), W. E. Wood (cg)

Galveston--E. H. Brown (g), A. Collier (ceg), A. J. Kainen (c), W. D. Parish (cg), K. V. Speeg (cg)

Haskell--C. Chinn (b)

Hondo--C. L. R. Holt, Jr. (gh)

Houston--L. M. Absher (abh), J. L. Adler (abdfh), J. R. Anderson (c), E. W. K. Andrau (cgh), L. T. Barrow (abeg), M. L. Benke (b), J. L. Bible (abdh), J. P. Black (b), A. Blanchard (b), P. H. Blanchet (h), L. W. Blau (bdh), T. W. Bonner (d), R. T. Booth (bd), O. L. Brace (bc), S. H. Buckley (Ruska Instrument Corp. representative), S. E. Buckley (g), J. M. Bugbee (gh), J. W. Byers (b), D. P. Carlton (abdeh), G. W. Carr (b), S. R. Casey, Jr. (h), S. K. Clark (gh), E. J. Coel (b), B. Cornelison (ah), I. H. Cram (abh), M. J. Davis (bdh), L. Decker (abcdefgh), J. H. Dunaway (bc), J. W. Eberman (bg), J. B. Eby (a), C. H. Fay (b), H. N. Fisk (gh), L. Franklin (egh), A. Frosch (bd), E. Frowe (ad), D. H. Gardner (bh), R. A. Geyer (ad), W. H. Goines (g), F. Goldstone (abdh), C. H. Gregory (abh), W. R. Griffin (dh), E. I. Grizzell (b), W. L. Grossman (bh), H. Guyod (d), W. Hafner (b), A. B. Hamil (b), J. W. Handin (eh), T. I. Harkins (b), R. Henquet (cd), L. B. Herring (ab), L. Horvitz (abd), L. G. Howell (abd), W. E. Hubbard (df), M. K. Hubbert (abdegh), J. S. Ivy (b), S. A. Judson (dh), F. M. Kannenstine (b), G. B. Lamb (abdh), J. E. La Rue (ab), R. J. Le Blanc (egh), W. B. Lee, Jr. (abh), E. G. Leonardon (bdfgh), F. E. Lozo, Jr. (acdeg), G. M. Mace, Jr. (b), E. J. Marti (bde), Joyce I. W. McCann (cdh), K. G. McCann (b), B. McCollum (bd), R. D. Miller (bcdh), R. R. Morse (bcefgh), L. M. Mott-Smith (ad), R. H. Nanz, Jr. (aefg), P. H. Nelson (e), L. L. Nettleton (abdh), L. J. Neuman (abd), W. J. Osterhoudt (beg), C. C. Palmer (bcd), M. H. Parks (bce), F. M. Purcell (abcdefgh), R. H. Ray (ab), F. W. Rolshausen (egh), N. A. Rose (g), R. A. Rowland (abgh), W. E. A. Ruska (d), Ruska Instrument Corp. (Corporation Member), W. M. Rust, Jr. (abd), R. L. Sargent (ab), L. A. Scholl, Jr. (abcdh), J. P. Schumacher (abdh), M. M. Sheets (bcefgh), G.G. Shor, Jr. (b), S. E. Sims (ab), M. M. Slotnick (abdh), A. E. Smith (abdh), N. D. Smith, Jr. (b), G. B. Somers (bcdh), C. D. Speed, Jr. (abdfh), T. B. Stanley, Jr. (ag), N. C. Steenland (dh), R. C. Sweet (abc), J. Taylor (b), R. E. Taylor (adeg), M. P. Tixier (bd), R. W. Walling (b), H. C. Warren (b), P. Weaver (bdfgh), R. A. Weingartner (abdf), O. Wilhelm (gh), A. G. Winslow (ag), G. W. Winter (a), A. Wolf (bdh), R. D. Woods (abcdefgh), S. P. Worden (a), F. R. Ybarguen (abcdefgh), H. M. Zenor (abcdefgh), C. C. Zimmerman (abdh)

Kingsville--C. C. Bajza (e), J. W. E. Edmonson (abdh)

Lamesa--B. F. Owings, Jr. (b)

Laredo--K. F. Keeler (cg), J. B. Ringwood (g)

Lockhart--F. W. Wiegand (abd)

Lubbock--W. H. Alexander, Jr. (cg), H. Klaus (abdh), L. T. Patton (b), R. Sidwell (cefg)

Midland--J. E. Adams (egh), L. W. Ashmore (bd), J. E. Bucher (bd), E. E. Conant (b), L. G. Cornish (abef), J. W. Daly (bd), G. R. Gibson (h), B. R. Haigh (a), T. F. Head (bc), W. L. Homan (ab), B. G. Hubner, Jr. (b), B. C. Hyde (g), F. F. Kotyza (abcdefgh), Jean Lewis (fh),

Texas--Concluded

Midland (concluded)--E. R. Lloyd (b), S. M. McDonald (bcefgh), M. H. McKinsey (ab), J. I. Moore (b), J. P. Rodgers (f), L. F. Uhrig (abcdh)
Pecos--J. W. Hood (g)
Port Aransas--G. Gunter (eg)
Port Arthur--I. W. Russek (be)
Randolph Field--T. C. Jafferis (c)
Roby--E. R. Beach (a)
Rock Springs--J. Harris (ab)
San Angelo--T. S. Cox (bd), R. D. Holt (g), T. W. Weinheimer (g)
San Antonio--G. M. Braun (abd), W. C. Ellis (g), J. N. Gragnon (b), A. F. Hasbrook (abe), M. S. Hathaway (bdef), A. A. Jergins (bh), J. W. Lang (g), F. W. Murray (c), P. E. Narvarte (b), E. W. Owen (ef), J. O. Parr, Jr. (abdh), D. E. Petty (abdeh), O. S. Petty (abdh), V. A. Petty, Jr. (adeg), D. H. Rowden (befgh), M. R. Sartain (abh), R. J. Scofield (ab), D. R. Semmes (c) E. A. Taegel (bh), J. A. Taylor (abd), R. A. Thompson, Jr. (g), T. S. West (bd)
Seguin--R. K. Blumberg (b)
Sherman--H. L. Schiflett (ad)
Sinton--R. M. Low (abcdefgh)
Snyder--D. C. Van Siclen (ah)
Stephenville--C. T. Rankin (a)
Sunray--S. G. Hardison (bdh)
Sweetwater--A. V. Hargis (be)
Texarkana--W. C. Wagner (bc)
Tyler--O. D. Brooks (b), J. R. Bunn (h), S. H. Eby (a), J. S. Hudnall (abgh), G. J. Loetterle (beg), E. A. Wendlandt (abh)
Waco--R. W. Baird (cg), T. E. Darby (h)
Whitesboro--M. T. Bentley (a)
Wichita Falls--R. J. Adams (bh), R. A. Crain (bd), D. E. Gee (bfh), L. P. Hodge (b), R. H. King (eh), J. R. Strong, Jr. (b)

Utah

Ephraim--R. B. Marston (g)
Eureka--T. S. Lovering (defgh), H. T. Morris (f)
Logan--W. C. Barrett (gh), J. E. Christiansen (g), G. D. Clyde (cg), W. Gardner (gh), V. E. Hansen (g), W. V. Iorns (g), O. W. Israelsen (g), C. W. Lauritzen (g), C. H. Milligan (g), A. D. Smith (cg), J. S. Williams (bgh)
North Logan--E. G. Hanson (g)
Ogden--J. A. Adams (cg), R. W. Bailey (g), G. W. Craddock (g), A. R. Croft (g), W. C. Goines (g), P. E. Packer (cg)
Provo--H. J. Bissell (a), G. H. Hansen (bdfh)
Salt Lake City--T. C. Adams (abcg), J. R. Barton (cg), A. B. Carpenter (c), A. L. Christensen (bcefgh), F. W. Christiansen (bfh), K. L. Cook (bdh), R. C. Culler (cg), A. J. Eardley (h), J. C. Eberhardt (c), W. M. Elsasser (cd), M. P. Erickson (fh), P. F. Fix (bcfgh), G. H. Gaul (ch), A. E. Granger (f), D. Hager (h), J. V. Hales (cdeg), H. B. Hawkes (cg), C. S. Howard (g), C. E. Jacob (abgh), C. S. Jarvis (egh), R. J. Lacy (bd), B. E. Lofgren (cg), W. B. Nelson (ceg), J. W. Odell (g), A. D. Peterson (bcdg), H. V. Peterson (bcg), E. H. Pickett (ceg), H. Schneider (bf), W. P. Somers (g), W. L. Stokes (gh), W. M. Webster (g), N. C. Williams (fh), M. T. Wilson (cg), G. B. Woolley (ae)

Vermont

Burlington--A. D. Butterfield (adh), C. G. Doll (h), E. C. Jacobs (bfh)
Montpelier--W. M. Cady (fh)
Morrisville--D. B. Wheeler (g)

Virginia

Alexandria--H. M. Bannerman (befh), G. D. Bath (d), J. E. Caskey, Jr. (ceg), E. C. T. Chao (abcdefgh), E. R. de Luccia (bg), F. P. de Percin (c), G. F. Kennedy (ae), Myrtle M. Kenney (a), E. Lipson (d), W. R. McCutchen (h), W. M. McMurray (c), J. A. Minogue (aceg), R. N. Nesbitt (befh), Marcella L. Phillips (cd), J. R. Richardson (a), R. A. Sanders (c), D. B. Sands (d), S. B. Solot (cg), W. C. Spreen (cg), J. P. Winner (c), J. E. Woolhiser (e)
Annandale--E. H. Bramhall (bcdh)

Virginia--Concluded

Arlington--H. W. Adams (cg), L. Alpert (ceg), L. R. Beard (cg), G. W. Brier (cg), C. R. Briggs (beg), F. M. Chace (f), P. F. Clapp (c), M. P. Connaughton (g), H. V. Darling (g), W. E. Davies (ag), H. Demboski (cg), J. W. Dixon (g), M. D. Dubrow (g), J. B. Edson (cd), W. S. Eisenlohr, Jr. (g), W. B. Eyestone (cg), W. R. Farley (g), L. A. Farrer (cg), J. R. Finton (ce), W. E. Fox (cg), Marian M. Frye (a), J. R. Fulks (c), C. S. Gilman (cg), L. C. Gottschalk (bg), R. G. Grassy (abcdefgh), J. P. Hagen (d), W. H. Haggard (c), F. Hall (ce), W. E. Harman, Jr. (a), C. Harmantas (c), D. R. Harris (c), M. F. Harris (c), R. B. Hohlt (abfgh), F. W. Hough (ab), H. H. Howe (abcd), J. L. Hudson (c), D. S. Jenkins (g), J. M. S. Kaufman (abcd), C. W. Kroll (a), E. S. Larsen, Jr. (f), H. Lemons (c), C. M. Lennahan (c), G. G. Lill (abcdefgh), R. H. Martin (c), W. F. McDonald (ceg), F. L. Meara (gh), C. P. Mook (c), G. W. Musgrave (ceg), E. R. Nelson (cdg), D. B. Newlin (a), T. J. Nordenson (g), H. O. Ogrosky (g), J. C. Owen (g), H. W. Palm (g), H. D. Parry (c), T. H. Pearce (b), R. C. Peavey (d), B. Perkins, Jr. (abcdfh), M. Rigby (eg), D. C. Ritchie (a), S. A. Schmitt (abcdefgh), J. Siegel (a), P. A. Siple (ch), F. F. Snyder (cg), T. E. Stewart (d), S. Teweles, Jr. (c), P. D. Thomas (a), H. D. Walker (a), W. G. Watt (ce), R. O. Williamson (a)
Ashland--P. P. Starke, Jr. (ce)
Austinville--R. B. Fulton, III (f)
Blacksburg--R. E. Bates (gh), T. W. Edminster (g), H. N. Holtan (gh), M. H. Kirkpatrick (gh), J. H. Lillard (g), P. Walker (gh)
Charlottesville--D. J. Cederstrom (fg), A. R. Green (g), O. D. Mussey (g), W. A. Nelson (bdeh), L. O. Quam (cg), A. Sinnott (fgh), L. B. Snoddy (d), R. H. Tice (g), D. S. Wallace (g)
Dahlgren--C. J. Cohen (fh), G. E. Merritt (b)
Dante--R. H. Wilpolt (bfg)
Ditchley--H. M. Ryder (gh)
Fairfax--S. Krasnow (abcdefgh)
Falls Church--G. L. Arnold (cg), L. P. Carstensen (c), D. H. Gould (c), B. Holzman (cg), L. A. Koffman (g), R. F. Kreiss (g), H. E. Landsberg (bch), L. Lassen (g), J. A. Lieberman (cg), W. J. Malloy (ce), G. C. Miller (d), J. J. Pellegrini (a), W. D. Romig (g), W. K. Schaub (gh), C. F. S. Sharpe (cg), T. S. Southwick (cg), H. Wexler (c)
Fort Belvoir--H. S. Aurand, Jr. (ag), T. B. Hunter (acg)
Hampton--R. K. Souter (cd), J. K. Thompson (c)
Langley--P. Donely (c)
Lorton--P. Bartsch (eg)
McLean--J. A. Eady (a)
Newport News--C. H. Hancock (b)
Norfolk--H. J. Fine (cg), W. J. Kotsch (c), F. R. Pollock, Jr. (g), E. H. Sheridan (ae), F. B. Whitney (abcdefg), P. C. Whitney (ce)
Richmond--S. S. Schworm (cg)
South Boston--W. E. Patten (g)
Vienna--P. Meigs (cg)
Wytheville--Jean Lowry (fh)

Washington

Chelan--R. O. Cox (c)
Coulee Dam--W. P. Greenwood (b)
East Stanwood--R. A. Skrinde (cg)
Ephrata--E. Nasburg (g), E. H. Neal (g)
Friday Harbor--E. F. Swan (ceg)
Gig Harbor--W. A. Smoker (cegh)
Metaline Falls--A. E. Buller (h)
Olympia--W. A. G. Bennett (fgh), F. B. Roberts (cg)
Prosser--R. W. Leamer (g)
Pullman--C. D. Campbell (bf), M. R. Carstens (g), H. E. Culver (bcf)
Richland--R. E. Brown (fh), D. J. Brumley (g), D. E. Jenne (cg)
Seattle--F. I. Badgley (c), M. L. Barad (c), C. A. Barnes (e), J. P. Bauer (c), C. H. Bowers (bc), F. H. Browning (e), A. S. Cary (h), P. E. Church (ceg), J. E. Colcord, Jr. (ag), A. S. Dereskevich (c), H. G. Dorsey, Jr. (c), H. A. Downs (ceg), M. Duffy (bcdeg), A. Ehrlich (c), R. S. Eustis, Jr. (c), R. E. Fuller (f), G. E. Goodspeed (bf), S. B. Grenell (a), G. F. Hopkins (g), R. E. Jentoft, Jr. (ce), R. Levine (c), J. H. Mackin (g), H. H. Martin (c), P. Misch (bh), F. C. Murphy (g), W. C. Russell (ab), W. L. Schallert (ceg), E. Sherrill (ceg), S. J. Sifferman (ceg), P. R. Stinchfield (c), E. G. Stoeckeler (g), T. G. Thompson (eg), C. L. Utterback (deh), H. O. Westby (g), C. L. Willis (bdfh), F. A. Zeusler (e)

Washington--Concluded

Shelton--H. K. Trobitz (cg)
Snohomish--R. D. DeSelle (g)
South Seattle--C. R. Gernert (a)
Spokane--M. R. Klepper (fh), J. S. Vhay (fh), A. E. Weissenborn (df)
Tacoma--D. G. Anderson (g), E. G. Bailey (g), G. L. Bodhaine (g), D. F. Calkins (g), M. D. Calkins (g), A. Johnson (g), H. B. Kinnison (g), F. F. Lawrence (g), C. C. McDonald (g), M. M. Miller (g), M. J. Mundorff (cgh), H. C. Riggs (g), W. H. Robinson (g), W. D. Simons (cg), F. M. Veatch (g)
Walla Walla--H. H. Helm (g), M. J. Ord (cg), T. F. Thompson (bfg)
Yakima--H. L. Swift (c)

West Virginia

Bluefield--R. M. Allen, Jr. (g)
Charleston--K. A. MacKichan (g)
Clarksburg--S. G. Highland (cg)
Huntington--F. B. Barkalow (g), W. T. Collins (cg), G. F. Connell (g), L. P. Gidley (g), W. C. Miller (gh), A. G. Schafer (g)
Inwood--A. F. Mish (a)
Morgantown--R. C. Colwell (c), W. D. Foster (cg), C. A. Myers, Jr. (cg), P. H. Price (bc), R. C. Smith (egh)
Parkersburg--H. F. Johnston (g)
Princeton--H. W. Straley, III (abcdefgh)

Wisconsin

Appleton--A. C. Braun (cg)
Beloit--C. Croneis (cegh), G. W. Holmes (g), J. D. Swannack (abg)
Chippewa Falls--H. H. Carter (ce)
Florence--J. W. Trow (gh)
La Crosse--A. D. Sanial (cg)
Madison--W. E. Bonini (a), R. H. Brigham (g), R. A. Bryson (c), W. J. Drescher (g), R. C. Emmons (adfh), F. C. Foley (g), R. M. Gates (dfh), James Hackett (g), H. J. Hunt (g), L. A. Joos (c), A. T. Lenz (cg), N. E. Minshall (g), S. M. Munson (ceg), J. E. Smith (c), V. E. Suomi (cg), C. B. Tanner (gh), J. G. Woodburn (g), G. P. Woollard (abd)
Milwaukee--G. M. Brune (g), S. Karrer (abcdefgh), A. R. Striegl (g), H. J. Thompson (cg)
Oregon--W. C. Walton (g)
Wausau--M. W. Kyler (cg)

Wyoming

Casper--G. W. Berry (be), G. A. Burton (abdh), C. Congdon (abcdefgh), J. R. Fanshawe, II (h), W. H. Fenwick (abdh), J. H. Fisher (fgh), W. E. Hall (abcefh), T. C. Hiestand (ab), C. H. Humphrey (acg), A. Junger (bfh), M. G. Schwab (g), K. van der Weg (bfh), A. L. Wilkinson (b)
Cheyenne--H. M. Babcock (g), R. T. Littleton (bg), C. C. Williams (efg)
Cody--M. M. Johnson (b), J. H. Osborne, Jr. (a)
Laramie--J. U. Biggers (cg), D. L. Blackstone, Jr. (abdh), F. W. Osterwald (fh), D. S. Turner (abefgh)
Lowell--H. P. Downey (abdefh)
Riverton--O. M. Hackett (efg), M. S. Petersen (g), M. L. Thompson (cg)
Rock Springs--W. T. Nightingale (bdfh), B. V. Savoy (cg)
Torrington--G. J. Staves (ab)
Worland--T. F. Hanly (g)

FOREIGN COUNTRIES

Canada (by post offices)

Antigonish, Nova Scotia--D. J. MacNeil (e)
Billings Bridge, Ontario--C. W. McLeish (d)
Bourlamaque, Quebec--F. W. Brown (d)
Calgary, Alberta--C. H. Acheson (bd), P. I. Bediz (b), L. I. Brockway (abd), R. W. Craig (b), A. W. Farmilo (abh), W. R. Hanson (cg), W. H. Hohag, Jr. (b), O. H. Hoover (cg), W. C. Howells (abfh), R. D. Hughes (h), R. C. Hyslop (abcdefgh), T. A. Link (h), F. B. Loomis, Jr. (cefh), J. H. McKeever (befgh), R. L. Mims (bdh), F. M. Mitcham, Jr. (b), R. G. Paterson (dh), E. G. Robinson (bc), T. Rozsa (b), J. O. B. Sanderson (befh), W. M. Small (ceh), R. C. Smith (ab), Maria Spencer (de)
Chalk River, Ontario--D. A. Keys (abd)
Corner Brook, Newfoundland--E. Hinton (cg)
Creston, British Columbia--G. Constable (cg)
Cumberland, British Columbia--A. F. Buckham (h)
Edmonton, Alberta--R. G. Mills (b), A. E. Pallister (abde), C. B. Selmser (dfh)
Gatineau (Mills), Quebec--T. Siurna (a)
Halifax, Nova Scotia--W. L. Ford (e)
Hamilton, Ontario--H. S. Armstrong (efgh), M. E. Woods (d)
High Prairie, Alberta--W. F. Albers (b)
Kingston, Ontario--E. E. Watson (e)
Kirkland Lake, Ontario--H. Hopkins (fh)
London, Ontario--R. W. Packer (ceg), E. G. Pleva (cg)
Manor Park, Forbes, Ontario--J. H. Meek (cde)
Montreal, Quebec--R. Boucher (g), G. D. Cartwright (c), H. M. Finlayson (g), J. E. Gill (h), P. A. Smith (ae), A. L. Washburn (cg)
Morse, Saskatchewan--V. Bychok (bh)
Nanaimo, British Columbia--J. P. Tully (ce)
Nickel Plate, British Columbia--E. B. Mayo (fh)
Oakville, Ontario--R. E. Hore (df)
Ottawa, Ontario--R. J. W. Douglas (h), J. A. Elson (g), E. A. Hodgson (b), J. E. Hodgson (bdh), R. F. Legget (bg), R. G. Madill (d), W. E. K. Middleton (c), A. H. Miller (abdh), J. L. Rannie (a), J. E. R. Ross (a), R. M. Stewart (abd), L. H. Wylie (d)
Peace River, Alberta--W. A. Reeves (ab)
Quebec, Quebec--G. O. Villeneuve (ceg)
Regina, Saskatchewan--W. M. Berry (g), D. McIntyre (cg)
St. Andrews, New Brunswick--H. B. Hachey (e), L. M. Lauzier (ce)
St. James, Manitoba--W. W. Ramsay (g)
Saskatoon, Saskatchewan--A. R. Byers (h), B. W. Currie (cd)
Sault Ste. Marie, Ontario--W. G. Wellington (cdg)
Toronto, Ontario--A. F. Beck (b), W. L. Brown (d), D. E. Burton (abcdefgh), W. O. Cartier (abd), G. D. Garland (abdh), L. Gilchrist (acd), R. L. Hearn (cdg), O. B. Hopkins (abd), G. R. Johnson (adh), N. B. Keevil (bdfg), G. B. Langford (fgh), H. T. F. Lundberg (adh), J. C. Morgan (g), L. W. Morley (abcdh), A. G. Petrie (c), P. S. Quan (g), J. T. Randell, Jr. (abdgh), J. C. Sproule (abcdefgh), A. K. Watt (g), E. W. Westrick (bcd), J. T. Wilson (h)
Trail, British Columbia--C. O. Swanson (def)
Truro, Nova Scotia--J. E. Blanchard (bd)
Val d'Or, Quebec--R. G. Hoiles (fgh), T. Koulomzine (d)
Vancouver, British Columbia--W. M. Cameron (ce), A. R. Clark (abd), G. L. Pickard (eg), C. E. Webb (cg)
Virginiatown, Ontario--J. W. Baker (df)
West Calgary, Alberta--C. E. Chesher (g)
Wolfville, Nova Scotia--H. L. Cameron (aefh)
York Mills, Ontario--O. Holden (g)

OTHER FOREIGN COUNTRIES (by countries)

Algeria--G. Grenet (bd)
Argentina--M. A. Balay (e), L. R. A. Capurro (e), H. Etchebehere (e), G. J. Heinsheimer (g), H. V. Iglesias (abce), M. F. F. Langmann (g), R. N. Panzarini (e), R. J. Perazzo (cg), O. Schneider (abcdefgh), L. Slaucitajs (deg)
Australia--G. Baker (abcdefgh), N. A. Boutakoff (eh), K. E. Bullen (b), S. W. Carey (abcdefgh), M. D. Garretty (h), D. F. Glynn (g), L. T. Guy (ag), W. D. Mott (bdeh), C. H. Munro (g), W. H. R. Nimmo (g)

OTHER FOREIGN COUNTRIES (by countries)--Continued

Azores--J. Agostinho (bcdef)

Belgian Congo--E. A. Bernard (cg)

Belgium--E.-J. Devroey (g), P. Evrard (abdfh), G. A. T. Heyndrickx (g), A. E. Lombard (gh)

Brazil--O. Barbosa (befgh), O. H. Dodkin (acg), J. S. Ferraz (cdeg), J. W. Forster (cg), A. H. Glaser (c), D. Guimarães (fh), H. J. Hakala (ad), P. L. Heslop (cg), L. A. Penna (abcdefgh), L. I. Price (e), R. R. Saldanha (b), W. B. Sherman (cd), H. O. Sternberg (cefg), J. P. Webber (c)

Chile--B. F. Grossling (abdh), G. Moore (cg), J. Muñoz-C (f), C. R. Thomas (h), A. Vidal C. (g)

China--J. Chang (g), J. T. Fang (a), C.-Y. Fu (abcdefgh), G. Hsu (c), S. H. Hsu (acg), K. S. Hua (g), J. H. Jean (g), T.-Y. Koo (g), P. Y. Lin (g), C. J. Liu (g), H.T. Liu (g), C. Loh (g), C.-C. Ying (a), T. Yu (fh)

Colombia--J. Escobar (g), T. E. Hobbs (bd), J. P. House (b), J. J. Lloyd (fh), V. E. Oppenheim (efh), L. E. Orduz (g), C. S. Ospina (g), J. E. Ramírez (abch), J. I. Ruiz (abd), W. Silva (b), G. Tama (g), P. M. Tucker (abd), F. Wiesner R. (g)

Cuba--J. M. A. Conde (eg), J. F. de Albear y Frânquiz (agh), J. R. Goberna (abcde), J. G. Montes (g)

Czechoslovakia--F. Kuska (a)

Denmark--A. I. Gregersen (abh), Miss I. Lehmann (b)

Dominican Republic--R. A. Delgado (g)

Egypt--A.-H. Abul-Fetouh (g), M. H. S. Barker (eg), E.-S. A. El-Sammy (g), A. Fadel (g), A. E. M. Hussein (g), A. H. Mitwalli (g)

El Salvador--J. E. Mejía (bfh), T. G. Moran (bg)

Ethiopia--J. R. Cornett (b)

Finland--P. Eskola (Corresponding Member), W. Heiskanen (abcdefgh), V. Väisälä (c)

France--M. H. Bordeaux (eg), P. Danel (eg), F. J. Malina (g), J. S. McNown (eg), G. Post (ceg), H. J. B. Putman (g), M. Schlumberger (bdh)

Germany--N. G. Anderson (c), W. Hiller (b)

Great Britain--J. Carr (ab), R. I. B. Cooper (bdef), E. Dews (ce), N. Frost (b), N. R. Hagen (c), R. A. Higazy (efgh), V. C. Illing (abeh), H. Jeffreys (b) (Corresponding Member), O. T. Jones (h) (Corresponding Member), G. M. Lees (abd), E. B. Lindsey (b), P. C. Mahanta (abdh), C. S. Piggot (ef), G. Seligman (ag), R. Stoneley (abceh), L. H. Tarrant (abcd), E. Tillotson (b), E. J. P. van der Linden (b), Mary C. Vogt (cf)

Iceland--G. Bodvarsson (fg), T. Einarsson (fh)

India--B. K. Banerjee (cg), S. K. Banerji (g), S. L. Benerjee (bcd), G. W. Baxter (abcdefgh), G. C. Chaterji (abg), A. N. D. Choudhury (abcg) (Life Member), O. N. Dhar (cg), K. V. Ekambaram (g), S. S. Gairola (abcdefgh), R. B. C. L. Handa (abgh), A. N. Khosla (abcdefgh), H. R. Pramanik (cg), M. B. Ramachandra Rao (bd), K. Ray (ag), K. R. Narayana Row (acg), P. A. Salim (g), R. S. Shrikant (abg), S. Singh (g), K. C. Thomas (cg), H. L. Uppal (abcdefgh), P. H. Vaidyanathan (g)

Indonesia--H. H. Brons (bd), J. K. Dahlberg (b), J. W. Gwinn (abh), N. B. Sauvé (abdh), H. P. Schaub (bfh), N. van der Sleen (abdfh)

Iraq--A. J. Abdullah (ce), M. S. Hantush (agh), H. Hotchkiss (abcdefgh), J. E. Woodburn (abcdefgh)

Ireland--H. R. McQueen (c), D. H. Shideler (c), J. Terebelski (c)

Israel--B. Aisenstein (fgh), S. Irmay (ceg), C. L. Pekeris (abch)

Italy--M. A. Boccalery (abd), M. Bossolasco (abd), P. Caloi (bfg), D. B. Heaney (b)

Japan--K. Hidaka (ceg), K. W. Johnson (c), T. Nagata (bdf), U. Nakaya (cg), E. Nishimura (abdfh), S. Suyehiro (bc), C. Tsuboi (abdh)

Jugoslavia--O. Meisser (abdh)

Kenya--D. K. Hamilton (g)

Mexico--A. Acuna O. (cd), R. F. Aldredge (b), J. C. Almanza (c), M. Alvarez, Jr. (h), A. R. V. Arellano (fgh), A. Benassini (g), G. D. Camp (abdgh), A. Contreras Arias (c) (Corresponding Member), L. F. Covarrubias (bh), E. Cravioto G. (g), A. de la O. Carreno (bdfg), S. H. Folk (dg), C. Fries, Jr. (f), A. García Q. (cg), A. R. Geyne (fh), R. Guiza, Jr. (fg), L. F. Gusêman (abh), F. C. Martínez (b), M. Medina (a), E. V. Miller (cfg), R. Monges López (ad), E. Ordoñez (f), B. F. Rummerfield (abdh), P. C. Sánchez (acg) (Corresponding Member), O. van Rossum (bf), I. F. Wilson (fh)

Netherlands--B. Baars (abdh), L. E. J. Brouwer (abfh), D. R. Brown (abcdh), B. de Blank (abh), H. M. E. Schürmann (abcdefgh), P. Tetrode (cde), J. T. Thijsse (eg), J. van Veen (eg), A. Van Weelden (abdeh), F. A. Vening Meinesz (abcdefgh) (Corresponding Member)

New Zealand--H. F. Baird (abdh), J. W. Beagley (abcdeh), B. W. Collins (cefg), J. Healy (bdf), W. M. Jones (abcdefgh), N. A. Mowbray (cg), B. H. Olsson (bdh), E. I. Robertson (bdfh), F. E. Studt (abcdefgh)

Norway--T. F. W. Barth (f), E. Raestad (g), S. Rosseland (ad), H. U. Sverdrup (cde)

Pakistan--A. M. Chaudhury (c), S. M. Niaz (g), M. S. Quraishy (ceg), A. J. Sherwani (acg), K. U. Siddiqi (bcdefg)

OTHER FOREIGN COUNTRIES (by countries)--Concluded

Panama--G. C. Bunker (g)

Perú--M. Casaverde R. (cdg), H. L. Crutcher (cg), G. E. Ericksen (f), A. A. Giesecke, Jr. (bcdh), H. Goller (bcdh), F. C. Nieri (abdfh), J. P. Pollock (f),

Philippine Islands--M. M. Aycardo, Jr. (abdfgh), S. R. de Guía (d), A. G. de Jesus (ae), C. E. Deppermann (cd), A. O. Hizon (abcg), C. M. Legaspi (abcdefgh), G. H. Newman (fh), C. B. Reynolds (bdfh)

Portugal--W. C. Huyler (c)

Portuguese East Africa--P. C. Barbour (a), J. C. Heggblom (abd)

Saudi Arabia--T. C. Barger (abcdefgh), R. A. Bramkamp (begh), J. A. McInnis (a), O. A. Seager (abd), C. S. Sharp (a)

South Africa--J. F. Enslin (ad), N. C. Fletcher (cg), B. D. Maree (abcdefgh), N. Shand (cg), A. M. van Wijk (abcd), O. Weiss (abcdefgh), C. L. Wicht (cg)

Southern Rhodesia--P. H. Haviland (acdfg), R. R. Staples (g)

Spain--V. A. Bray (h), A. Due (abc)

Sweden--B. Hellstrom (g), D. F. Rex (abcegh), C.-G. Rossby (ce), K. J. M. Sundquist (g), P. W. Werner (g)

Switzerland--P. H. Butticaz (bh), N. Oulianoff (abcdefgh), H. J. Tschopp (bdefgh)

Trieste--C. Morelli (abcdh), S. Polli (ce)

Tunisia--D. Keppel (abfh)

Turkey--K. Ergin (abdeh), T. H. Lipscomb (gh), H. F. Sagoci (abd) (Life Member), S. Yungul (bdg)

Uruguay--C. A. Giavi (g), J. C. Roletti (d)

Venezuela--V. A. Acheson (abcdfh), P. I. Aguerrevere (bdg), S. E. Aguerrevere (abc), A. E. Berndes, Jr. (d), G. R. Brotherhood (abcdefgh), P. F. Browning (aeh), C. O. Clark (g), C. C. Cody (bfh), P. P. Conrad (abcdegh), H. L. Copeland (bh), J. H. Deming (bdh), J. E. Dorris (bh), W. R. Dortch (b), W. E. Franks (abdfh), P. W. Gester (b), A. J. Hanners (bdfg), E. F. Helser (abh), G. R. Heyl (fh), P. Jacobsen, Jr. (abdh), J. F. Judson (b), H. P. Laubscher (bfh), R. H. Mansfield (bdh), L. A. Martin (b), J. B. McKee (abe), J. H. McLay (abefh), L. J. Medina (g), H. R. Moorman (abd), P. Otamendi-Blanco (aegh), J. H. Pantin (abcdefgh), W. J. Pfeiffer (abd), N. H. Prade (b), R. H. Robie (abcegh), A. C. Romero (ad), C. G. Schauble (b), R. H. T. Schut (bh), R. G. Sohlberg (bfh), H. W. Thoms (cg), A. J. Vollmer (g), N. E. Weisbord (acefg), E. H. Wenberg (ad), F. W. Wright, Jr. (cdfh), M. W. Zaikowsky (be)

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Climatology: Appointments pending

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Honors and Awards: Merrill Bernard (Chairman), (other appointments pending)

Permanent Research Committees (Hydrology)

(Note: Terms of appointment expire on June 30 of the year indicated.)

Chemistry of Natural Waters: W. W. Hastings (Chairman), Joseph F. Poland (1951), Melvin Romanoff (1951), H. A. Stoltenberg (1951), M. R. Huberty (1952), Karl F. Keeler (1952), S. Kenneth Love (1952), Russell M. Jeffords (1953), Paul Weaver (1953), (another 1953 appointment pending)

Dynamics of Streams: J. W. Johnson (Chairman), Carl F. Izzard (1951), Francis F. Escoffier (1952), H. V. Peterson (1952), Ralph W. Powell (1952), Paul Baumann (1953), Whitney M. Borland (1953), Stafford C. Happ (1953)

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Ground Water: Joseph F. Poland (Chairman), M. L. Brashears, Jr. (1951), C. N. Johnston (1951), H. E. Thomas (1951), Harry F. Blaney (1952), Edward B. Burwell, Jr. (1952), William F. Guyton (1953), (other appointments pending)

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Volume No.	Year	Title	No. pages	Price postpaid
1	1920*	Transactions (Reprinted Circular Series, National Research Council No. 11)	57	$0.60
2	1921*	Transactions (Bull. National Research Council, No. 17)	108	1.50
3	1922*	Not published	..	...
4	1923*	Transactions (Bull. NRC, No. 41)	150	2.00
5	1924*	Not published	..	...
6	1925*	Transactions (Bull. NRC, No. 53)	80	1.00
7	1926*	Transactions (Bull. NRC, No. 56)	134	1.25
8	1927*	Transactions (Bull. NRC, No. 61)	297	3.00
9	1928*	Transactions (Bull. NRC, No. 68)	103	1.00
10-11	1929-30*	Transactions (all Sections)	314	1.50
12	1931*	Transactions (all Sections)	229	1.50
13	1932*	Transactions (all Sections)	401	2.00
14[a]	1933*	Transactions (all Sections)	521	2.50
15	1934*	Transactions Part I (all Sections except Hydrology)	258	1.25
	1934*	Transactions Part II (Hydrology)	376	1.50
16	1935	Transactions Part I (all Sections except Hydrology)	364	2.00
	1935*	Transactions Part II (Hydrology)	166	1.50
17	1936	Transactions Part I (all Sections except Hydrology)	260	1.50
	1936*	Transactions Part II (Hydrology and Regional Meetings, Hydrology)	304	2.00
18	1937*	Transactions Part I (all Sections except Hydrology)	264	1.75
	1937*	Transactions Part II (Hydrology and Regional Meetings, Hydrology)	300	2.25
19	1938*	Transactions Part I (all Sections)	585	3.50
	1938*	Transactions Part II (Regional Meetings, Hydrology)	159	1.25
20[b]	1939	Transactions Part I (Regional Meetings, Hydrology)	140	1.25
	1939	Transactions Part II (Symposium on floods)	94	1.00
	1939*	Transactions Part III (all Sections except Hydrology)	250	1.75
	1939	Transactions Part IV (Hydrology)	257	1.75
21	1940	Transactions Part I (Stanford University, Regional Meetings, Hydrology)	144	1.25
	1940*	Transactions Part II (Washington Annual Meetings, all Sections)	632	3.75
	1940	Transactions Part III (Richmond Symposium and Seattle Regional Meetings, Hydrology)	285	1.75
	1940	Transactions Part IV (Columbus symposia: Applications of mathematics in the earth-sciences and Hydrologic problems in the Ohio and Michigan basins	86	1.00
22	1941	Transactions Part I (Sacramento Regional Meeting, Hydrology)	216	1.50
	1941	Transactions Part II (Washington Annual Meetings, (all Sections except Hydrology)	368	2.50
	1941	Transactions Part III (Washington Annual Meeting, Hydrology)	452	3.00
23	1942	Transactions Part I (Dallas and Pasadena Regional Meetings, Hydrology)	172	1.25
	1942	Transactions Part II (Washington Annual Meetings, all Sections)	570	4.50
24	1943*	Transactions Part I (Washington Annual Meetings, all Sections except Hydrology)	332	3.50
	1943*	Transactions Part II (Washington Annual Meeting, Hydrology)	454	4.00

[a] Although Transactions of 1933 as a whole are exhausted, the Papers and Reports of the following Sections are available: Meteorology, 40 pp., $0.40; Hydrology, 185 pp., $1.50.

[b] In addition to the Parts listed, a few complete sets of the 1939 Transactions are available at a price of $5.25 for a set.

Volume No.	Year	Title	No. pages	Price postpaid
	1943	Transactions Part III (Corvallis Regional Meeting, Hydrology, and Western Snow-Conference) and Addendum	105	$1.00
25	1944	Transactions Part I (Berkeley Regional Meeting, Hydrology, and Western Snow-Conference)	187	2.00
	1944	Transactions Part II (Washington Annual Meetings, General Assembly, Geodesy, Seismology, Minutes all Meetings)	203	2.00
	1944*	Transactions Part III (Washington Annual Meeting, Meteorology	138	1.50
	1944*	Transactions Part IV (Washington Annual Meeting, Terrestrial Magnetism and Electricity, Oceanography, Voocanology, and Tectonophysics)	142	1.50
	1944	Transactions Part V (Washington Annual Meeting, Hydrology: Reports)	160	1.50
	1944	Transactions Part VI (Washington Annual Meeting, Hydrology: Papers).	236	2.00
26	1945	Transactions, 3 numbers (first bimonthly number issued in August)	482	**
27	1946	Transactions, 6 numbers	926	**
28	1947	Transactions, 6 numbers	980	**
29	1948	Transactions, 6 numbers	956	**
30	1949	Transactions, 6 numbers	950	**
31	1950	Transactions, 5 numbers thus far, including October 1950 issue	808	***
Special	(1920)*	A survey of research problems in geophysics (Reprint and Circular Series NRC, No. 11)	57	0.60
Special		Bibliography of Hydrology, United States of America:		
	(1937)*	Years 1935 and 1936	78	0.30
	(1938)*	Year 1937	68	0.30
	(1939)*	Year 1938	78	0.30
	(1940)	Year 1939	86	0.50
	(1941)	Year 1940	90	0.85
		Years 1941-1950 in preparation (Oct. 1950)	. .	. . .
Special		List of Members and Officers:		
	1948	July 10, 1948	79	1.00
	1950	September 10, 1950	116	1.50

*Out of print.

** The price of each issue of the bimonthly _Transactions_ is $1.50, except for the issue of August 1948 which is in two parts, the first being the regular scientific material and information on AGU affairs, and the second being a list of members and related material. The price of the first is $1.50, and the second $1.00. The three issues of the _Transactions_ of 1945 are available for $3.75, and the six issues of each of the years 1946, 1948, and 1949 are priced at $7.50. Only the last three issues of the _Transactions_ of 1947 are still available and are priced at $3.75.

*** Subscriptions to the Transactions of 1950 are $9.00 each.

Index--At this time (October 1950), an index of the first 25 years of the _Transactions_ (1920-1944) is in process of publication, with the price still uncertain. Since 1945, an annual subject and author index has been published in each December issue.

In addition to the publications noted above, 49 special exhibits (chiefly maps) were prepared in 1939, these relating to the work of the Special Committees on the Geophysical and Geological Study of Ocean Basins and of Continents for the Seventh General Assembly of the International Union of Geodesy and Geophysics. Ozalid prints of these will be made on order. Information concerning them will be supplied on application.

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